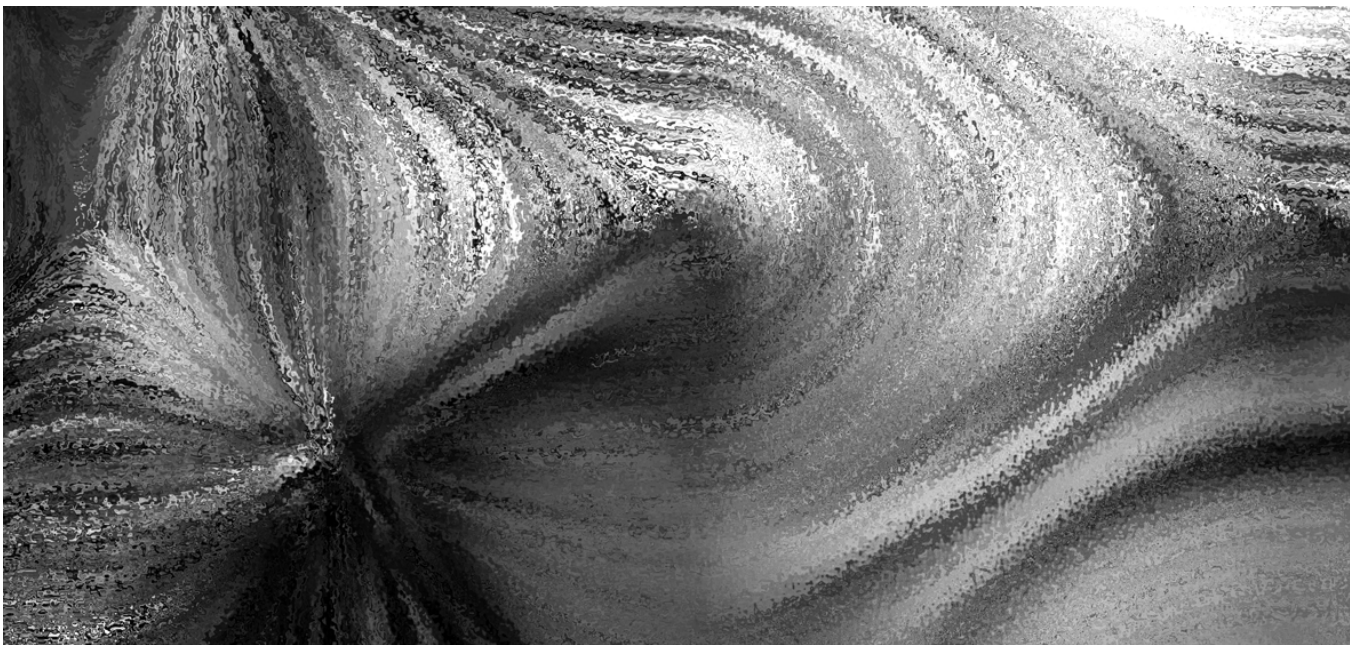
Measurement & Testing of Physical Performance



FELTHAM PRESS

Introduction

The aim of this set of notes is to provide an introduction to, and a summary of, simple investigative techniques that can be used for the measurement of various aspects of physical performance, without the need for advanced apparatus.

They act as an introduction to the practical aspects of courses in exercise physiology and human biology, but they are in no way intended to be used in isolation, independent of the supervision of appropriately trained personnel, nor are they intended to substitute for detailed practical instructions provided by the suppliers of the relevant pieces of apparatus. These notes also cover the main theoretical content in this area of post-16 Sport Studies and Physical Education syllabuses, and to this end consideration is given to the validity and reliability of the tests.

The Notes for Supervisors are included not only for those staff who may be relatively new to the specific considerations of exercise physiology, but also for the benefit of the many students who increasingly interact in practical investigations, both in the classroom/laboratory situation, and often outside of it when conducting physiological based project work – at which times they may find themselves unwittingly acting in the role of supervisors. These notes should also serve to remind all those involved, of the care that must be taken at all times, even in seemingly innocuous situations.

Particular thanks are due to Owen Jenkins, Lecturer in Exercise Physiology at Wigan and Leigh College for invaluable help in the compilation of these notes, especially with regard to the testing protocols and the data produced.

Contents

NOTES FOR SUPERVISORS 5-7

1 MEASURING TECHNIQUES

1.1 Measuring heart rate 9

1.1.1 Using the pulse 9–10

1.1.2 Using a heart rate monitor 11–12

1.2 Measuring blood pressure 13

1.2.1 Arterial blood pressure 13

1.2.2 Venous blood pressure 14

1.3 Measuring Breathing 15

1.3.1 Use of the spirometer (spirometry) 15–22

1.3.2 Breath volume bags 23

1.3.3 Pocket spirometers 23

1.3.4 Simple apparatus to determine the CO_2 Index 24

1.3.5 Stethograph 24

1.4 Miscellaneous Measures 25

1.4.1 Body fat 25

1.4.2 Flexibility 25

1.4.3 Strength 25

1.4.4 Balance, agility, co-ordination, and limb speed 25

continued....

Contents *continued*

2 TESTING OF PHYSICAL PERFORMANCE

2.1 **Further notes on the use of students in investigations of physical performance** 27-32

2.1.1 Health related fitness testing and monitoring in Schools 33-35

2.1.2 General References 36

2.2 **Step test** 37

2.3 **Shuttle run test** 38

2.4 **Treadmill tests** 39–42

2.5 **Cycle ergometer** 43–44

2.5.1 Heart rate tests (i) PWC_{170} (ii) VO_2max 45-48

2.5.2 Energy output 49

2.5.3 Power output 49

2.6 **Additional power tests** 51

2.6.1 Sargent vertical jump 51

2.6.2 Standing long jump 52

2.6.3 Margaria-Kalamen stair test 53

2.6.4 Validity of power tests 53

3 ASSIGNMENTS and SOLUTIONS

3.1 **Assignments** 55–64

3.2 **Solutions** 65–69

Notes for Supervisors

Notes on the use of Students in the Measurement and Testing of Physical Performance

These notes are an attempt to review the information currently available on the subject, and of what is considered to be good and safe professional practice in carrying out the tests outlined in this pack. They do not themselves constitute a definitive analysis or recommendation of safe practice, the responsibility for which rests with the supervisors.

It would appear that there is no clear policy relating specifically to such non-invasive, non-therapeutic physical tests as described here. However, tests involving human subjects must only be carried out under the supervision of a suitably qualified and responsible person. Supervisors of such tests do have a clear responsibility and legal obligation to take care of the health and safety of any person who may be affected by their acts or omissions. Codes of Safe Practice in educational establishments may vary from area to area, and from institution to institution, and the Supervisor has a duty to be aware of the relevant Health and Safety requirements.

COSHH Regulations/Guidelines must be followed in all respects.

All teachers are expected to exercise the same care for their students as would any reasonably careful parent when looking after her/his own children.

The exercise involved in the tests outlined here does not exceed that normally undertaken in supervised School/College physical education activities. The difference lies in the actual measuring techniques, which should only be undertaken by a suitably qualified member of staff, with a full understanding of the procedures involved.

Needless to say, the subject should be in good health. However, the subject may be reluctant to reveal the nature of a condition they might be suffering from, or even be unaware of its existence. Anybody who is medically excused normal physical education activities should not be the subject of any investigation into the effect of exercise on heart rate and/or respiration.

No pressure whatsoever must be exerted on the subject to take part in the test activity. It can be forgotten how difficult it may be for a young person to resist peer pressure, or even the gentlest persuasion when this comes from a member of staff.

One of the most difficult aspects of the testing procedure to control is that of interaction between participants. Certainly no element of competition should be allowed to enter the proceedings. Conversely, some subjects may deliberately 'under-achieve' as a result of such

interaction. Therefore, although difficult to organise in the normal School/College situation, it is preferable that participants should not be exposed either to each other, or an audience, whilst under test.

It is generally thought advisable that prior informed consent be obtained for all investigations using students as the subjects. In the case of those under 18, such prior consent should be obtained from both the subject and the parent(s) or legally authorised representative. However, the DES (1978) comments that:

"as it is likely to be difficult to establish that a pupil undertook the experiment in full knowledge of the possible hazards, and with his/her full consent, teachers may consider it advisable to avoid all such experiments with pupils under 16."

Prior informed consent would be obtained by having the subject and the parent(s) or legally authorised representative read and sign an appropriate document, an outline example of which is provided.

In addition to all these precautions, standard professional insurance via the local education authority, school/college, and/or teachers' union should be available.

Sample Prior Informed Consent Form

Title of Investigation or Experiment: _____

Objectives: _____

Description of Procedure: _____

_____

Questions: All questions relating to the investigation or experiment will be answered in full.

Safety: All the procedures to be used in this investigation/experiment are widely and commonly used in Schools and Colleges, and although all activity involves some risk of an accident, the risk of harm in this investigation/experiment is no greater than in normal everyday life, or than in a supervised physical education lesson.

Right of Withdrawal: You are absolutely free to withdraw from the investigation/experiment at any time. If during the investigation/experiment you feel in any way uncomfortable and wish to stop, you should do so.

Reassurance of Confidentiality: All information obtained as a result of the investigation/experiment will be treated confidentially.

Availability of Results: The data may be recorded manually, and/or stored on a computer, but not in association with your name. You are entitled to a copy of your own results on request.

Use of Results: The data may be used in discussions and/or as part of assignments or projects, but not in association with your name. They will only be used to illustrate general physiological principles, and will not be used for diagnostic or any other purposes

Statement of Consent: I fully understand the nature of the tests, and agree to participate in this investigation/experiment. To the best of my knowledge I suffer from no illness or condition that will:

i prevent me from successfully completing the tests,

ii be made worse in anyway by my taking part in the tests.

Name of Subject: _____

Signed: _____

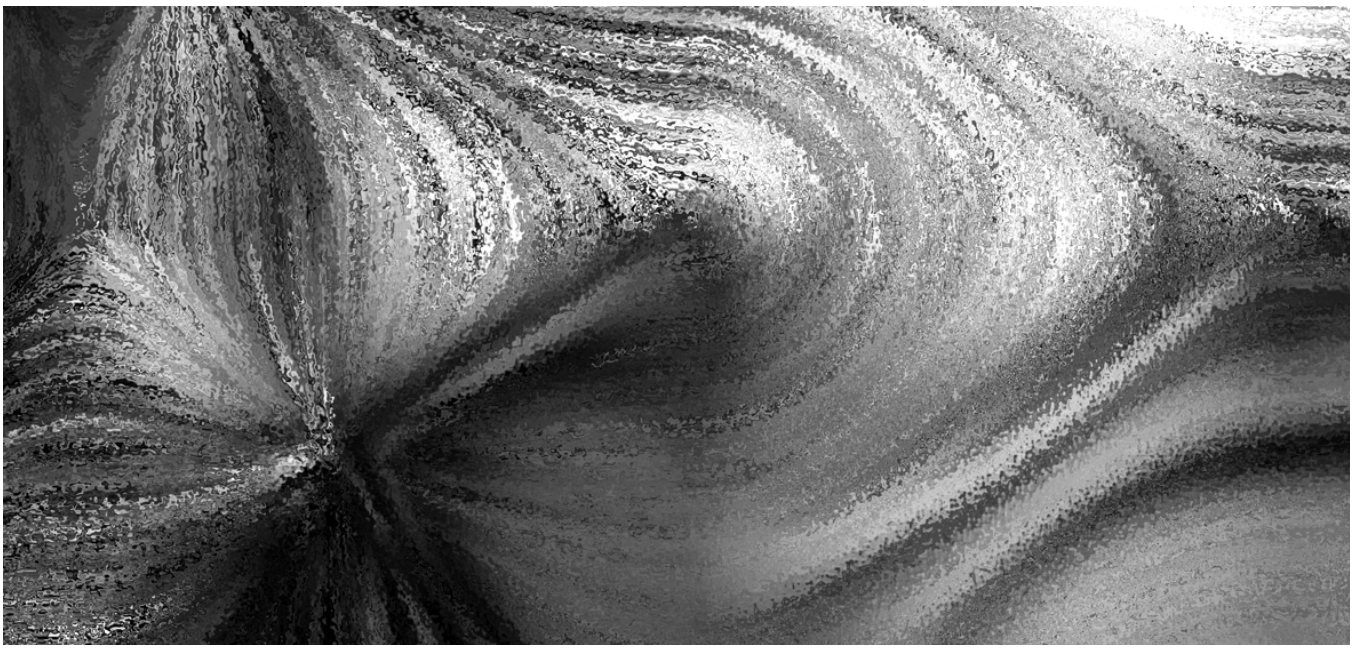
Date: _____

Name of Parent or Legally Authorised Representative: _____

Signed: _____

Date: _____

1 Measuring Techniques

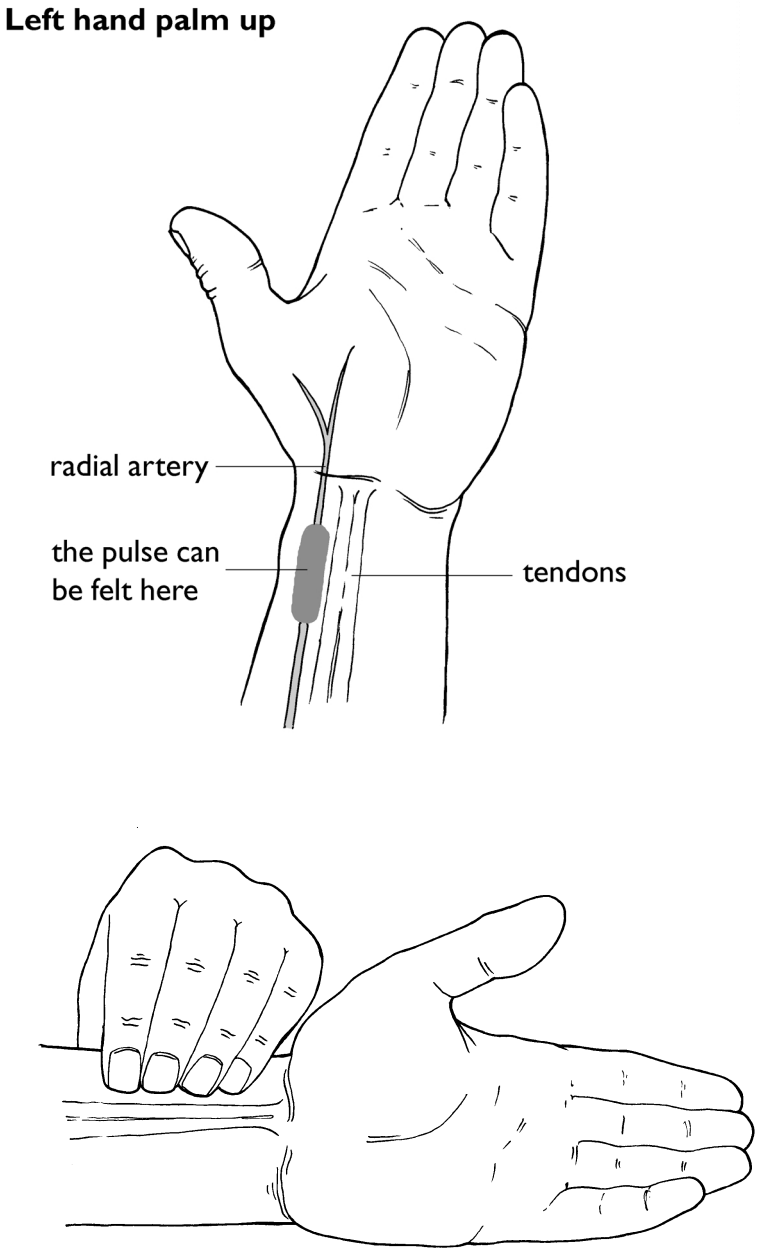


1.1 Measuring Heart Rate

1.1.1 Using the Pulse

The pulse can be felt in the radial artery at the wrist as shown in Figure 1. This is preferable to the use of the carotid pulse in the neck, which is not recommended, as the technique itself can induce changes in the pulse.

Figure 1: *Feeling the pulse at the wrist.*



Method

- Arrange a suitable place for the subject to lie flat on their back.
- Allow them to settle for two minutes.
- During this time locate the pulse in the left arm as illustrated.
- After 2 minutes count the pulse by starting with 0; e.g. count 0, 1, 2, 3, 4 up to 30, starting the stop watch as you count 0, and stopping it as you count 30.
- Record the number of seconds for 30 pulses.
- It is possible to count for a shorter period e.g. 6 seconds, but the longer the counting time, the more accurate is the conversion to beats per minute (bpm)
- At the end of counting, leave them at rest for a further 2 minutes.
- Repeat the 30 pulse count procedure.
- Allow to rest for 2 minutes.
- Repeat the 30 pulse count procedure again.
- Record all your results in a suitable table.

Resting heart rate can be taken as an indicator of the subject's status, for example some advise that it is best not to train if the resting heart rate is 10% above the normal rate for that person. Rusko suggests that if after lying down for 10 minutes, the pulse is taken 12 seconds after standing, for a count of 6, and 90 seconds after standing, for a count of 30, and converted to bpm; any rise in these rates (especially the second count) from day to day, can be an indication of overtraining.

1.1.2 Using a Heart Rate Monitor

In recent years, electronic heart rate monitors (HRM's) have become increasingly popular among both amateur and professional sports people as a means of controlling and monitoring training. Indeed, keep-fit enthusiasts who like to apply a 'scientific' approach to their work-outs find the new generation of instruments both simple and rewarding to use. Clear advantages offered by HRM's over manual pulse-taking are that heart rate can be continuously measured over extended periods of time, and also during a wide range of physical activities which do not lend themselves to periodic bouts of wrist holding - swimming for instance. Technological improvements have meant that nowadays the compact design of the instruments means that they do not restrict the wearer in any significant way.

The Heart Rate Monitor

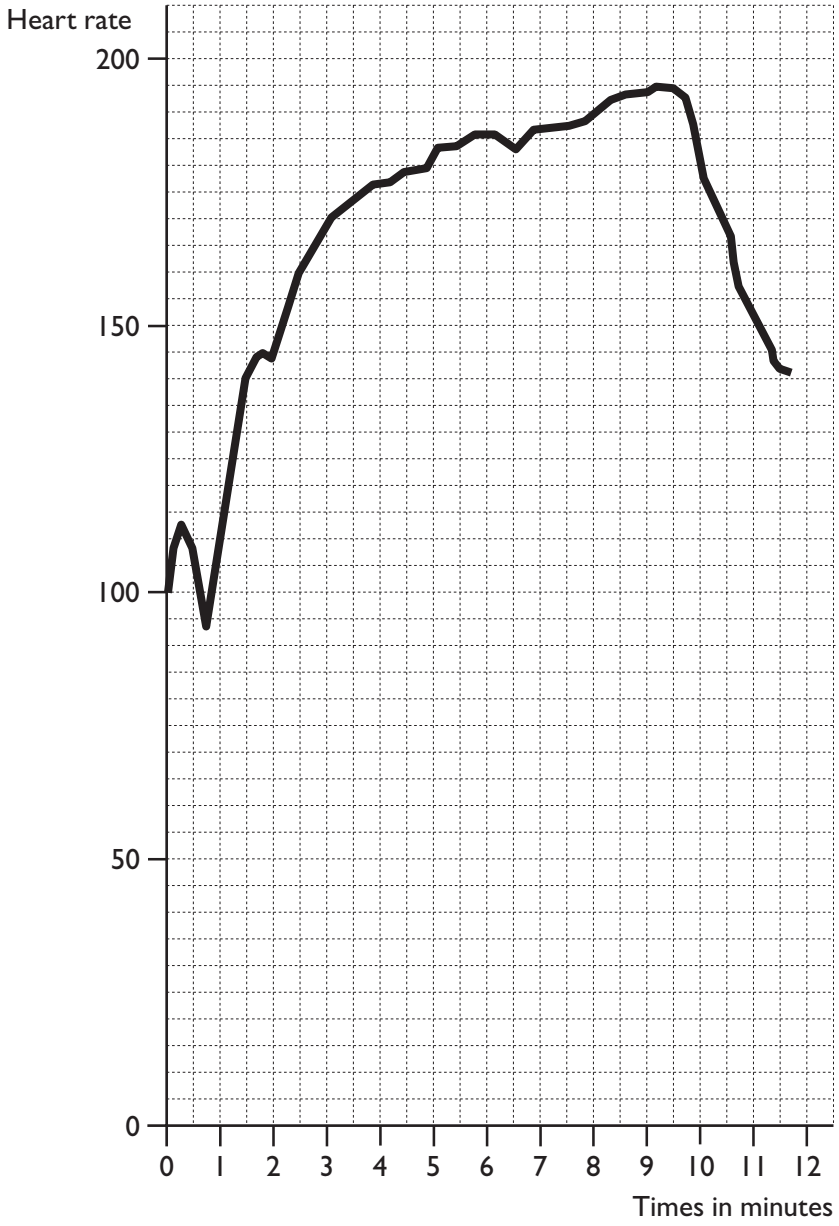
The most popular type of HRM has two components; the transmitter, in the form of a chest band with integral electrodes; and the receiver, which resembles a wrist watch in appearance. The range of the transmitter is about 1metre; this is not a great distance but it does not usually create any practical problems. The receiver, depending on the model and the cost, may give a simple digital display of current heart rate, or it may be capable of storing heart rate data in a number of files which can be retrieved either manually or down-loaded to a PC. This latter facility is invaluable when working with groups of students, as data from up to eight exercise sessions can be stored, and print-outs obtained from the computer for inclusion in student project files. (See Figure 2.)

Working with an HRM

These instruments are very versatile and no doubt, with the information provided by the manufacturer, teachers will devise a range of worthwhile activities. In the light of this, it is perhaps best here simply to give an illustrated example.

The activity illustrated is a progressive maximal test performed on a cycle ergometer. In this instance the heart rate was recorded at 15 second intervals. The pattern of the response in terms of heart rate in relation to the increasing work load can be clearly seen from the shape of the graph, and the listings give actual recorded values. This data is important in its own right, but could also be used to predict maximum aerobic capacity (VO_2 max). Recovery rate from exercise can also be accurately determined.

Figure 2: *Computer print out of heart rate 'profile' from data gathered at 15 s intervals from a maximal cycle ergometer test. Modified after Polar HRM.*



Time/minutes	Heart rate values at 15 second intervals											
0	103	111	105	94	108	125	140	143	142	151	158	162
3	167	170	172	174	175	174	177	178	179	180	180	183
6	184	184	183	180	184	184	185	186	186	188	190	191
9	192	192	193	192	192	187	175	170	164	155	150	146

Modified after "Working with an HRM' Polar.

1.2 Measuring Blood Pressure

1.2.1 Arterial blood pressure

There is no simple relationship between arterial blood pressure and exercise. Arterial blood pressure is difficult to measure under the conditions of most simple fitness tests due to the movement of the subject, and without long term prior knowledge of the blood pressure of the subject, it is difficult to assess its significance. Also the technique depends on compressing an artery and shutting down the flow of blood to the arm (a fairly drastic manoeuvre), and detecting at what pressure(s) the blood flow returns. There are problems with the accurate use of a stethoscope for this purpose, and although electronic measures avoid the use of the stethoscope, they do introduce complications of their own.

Standardisation It is important therefore that those involved fully understand the basis of blood pressure measurement, and that it only be carried out by, or under the supervision of, suitably qualified personnel, under standardised conditions; for these reasons the practical determination of blood pressure is not dealt with here. An inaccurate measurement of blood pressure is far worse than no measure at all.

Units Blood pressure is still quoted in units of millimetres of mercury (mm Hg), which relates to measuring the pressure in the cuff by means of a mercury filled tube or manometer. Conversion to SI units was not insisted on due to the possibilities of errors when dealing with patients in a clinical situation. Measuring the pressure in the cuff by means of a mercury manometer is still the preferred method (although the aneroid type is also widely used), due to the unreliability of most affordable electronic measures.

The systolic pressure is written first and the diastolic pressure second. Typical figures are given as 120/80 mm Hg (Conversion factor: mm Hg divided by 7.5 = 15.8 kPa/10.5 kPa!). The blood pressure increases with age in adults, and there is no clear division between ‘normal’ blood pressure, and 'high blood' pressure (hypertension).

Anxiety Allowance must also be made for ‘white coat’ hypertension, that is raised blood pressure as a result of anxiety about the test. This can raise the diastolic blood pressure to 120 mm Hg quite easily. An inaccurate reading of ‘high blood pressure’ can be self-fulfiling. One suggestion for estimating an ‘average’ systolic blood pressure is 100 plus the age of the subject.

Pulse Pressure The difference between the systolic and diastolic pressure is known as the ‘pulse pressure’, which is normally between 35-50 mm Hg. Some suggest that the ‘pulse pressure’ allows a crude estimate of the stroke volume of the left ventricle to be calculated, but there is no simple relationship between the two.

1.2.2 Venous Blood Pressure

This can be measured without interfering in any way with normal body function. With the arm held at the side the distension of the hand and forearm veins is noted. Standing next to a vertical flat surface, such as a wall, the arm is raised to be level with the heart, in which position the veins should still be distended. This position is marked, and the arm is then raised by an assistant, until the veins are seen to collapse. This new position is marked, and the difference between this and the previous position noted in centimetres as distance 'd'. The venous pressure can be calculated from the formula:

$$(d - 10) \times \frac{1.055}{13.55} \times 10 = \text{answer in mm Hg}$$

1.3 Measuring Breathing

SPECIAL SAFETY NOTE

Experiments involving unusual ventilation of the lungs can be dangerous to those suffering from asthma, bronchial disorders of any kind, or epilepsy. Supervisors should be aware of the status of their subject's health, possible consequences arising from any condition, and the necessary First Aid procedures.

1.3.1 The Use of the Spirometer (Spirometry)

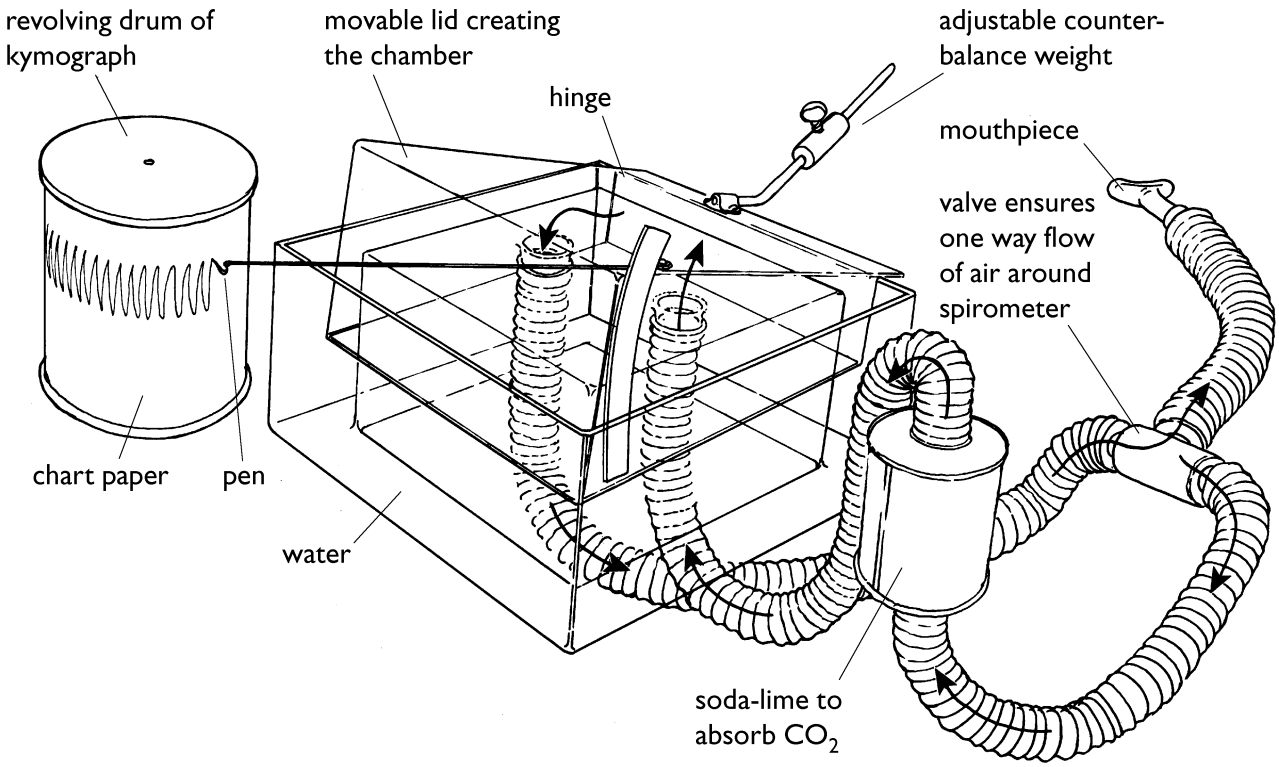
The Box Type Spirometer The spirometer commonly used in schools and colleges is of the box type shown in Figure 3. The apparatus consists of a water-filled tank with a hinged, wedge-shaped float finely balanced over water. The float is hollow with a volume of approximately 9 dm^3 (litres) and its lower face is open. The volume of gas enclosed by the water and the top and sides of the float represents the 'breathing mixture'. It is important that the float is perfectly balanced so that it can move up and down freely as a subject breathes the 'breathing mixture'. By using a nose-clip and a well-fitting mouthpiece the subject is isolated from the room air and breathes only from the closed system of the spirometer.

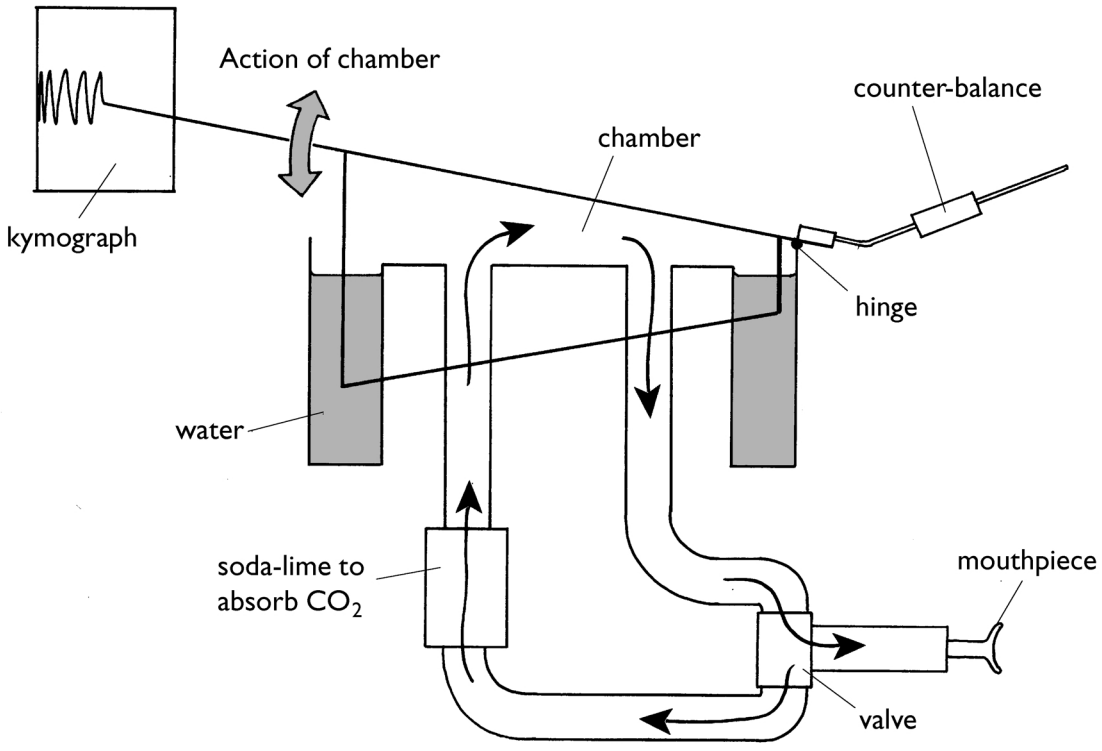
Hygiene It has been found that cardboard disposable mouthpieces, whilst offering the advantage of hygiene, become too 'leaky' when subjected to more than a very few breaths. Rubber mouthpieces are to be preferred, although students will complain of the taste, the drying of the throat, and of course the saliva. (Keep lots of paper towels handy). Sterilise your mouthpieces in Milton solution. The spirometer should be kept clean, and the breathing hose and non-return valve should be periodically sterilised (If the valve contains metal parts avoid any chlorine-based sterilants, but give it frequent washes in warm soapy water).

Practice In order to allow students to accustom themselves to breathing through a mouthpiece there is the option of redirecting the flow of gas so that the room air is breathed, this will not cause the float to move.

Measures The spirometer can be used to measure breathing volumes, breathing rates, and oxygen consumption.

Figure 3: *Box-type Spirometer. When the subject breathes in, air is removed from the chamber, so it moves down. When the subject breathes out, air is returned to the chamber, so it moves up. These movements are recorded, usually by a pen which is attached to the chamber marking squared paper on a revolving drum (a kymograph), or by electronic means.*





Measuring Static Volumes with the Spirometer

It is a relatively simple matter to measure the following volumes with air in the float: tidal volume (resting), minute volume, inspiratory reserve volume, expiratory reserve volume, and vital capacity. If these are measured at rest they are referred to as 'static volumes', as opposed to 'dynamic volumes' which are measured during exercise.

A pen attached to the float will create a trace on a kymograph drum rotating at 1 mm sec^{-1}. For determination of minute volume (tidal volume × breathing rate per minute) it is necessary to put time markers on the kymograph chart using a stopwatch. It is also important that the chart paper is calibrated. This can be done by first allowing the pen to contact the chart paper; then the float can be moved through a distance corresponding to 1 dm^3. This movement will translate into a mark on the squared chart paper. Provided the relative positions of the pen and kymograph do not subsequently radically alter then the calibration can be applied to an experimental trace:

e.g. 1 dm^3 = 2 cm (4 squares).

Figures 4 and 5 show the kind of traces that are obtained.

Figure 4: *Normal Tidal Breathing trace. Tidal volume and ventilation rate can be determined at rest and after exercise, and the minute volume or minute ventilation or respiratory minute volume, can be calculated, i.e. tidal volume multiplied by ventilation rate per minute (from 8 dm^3 at rest to 100 dm^3 during exercise).*

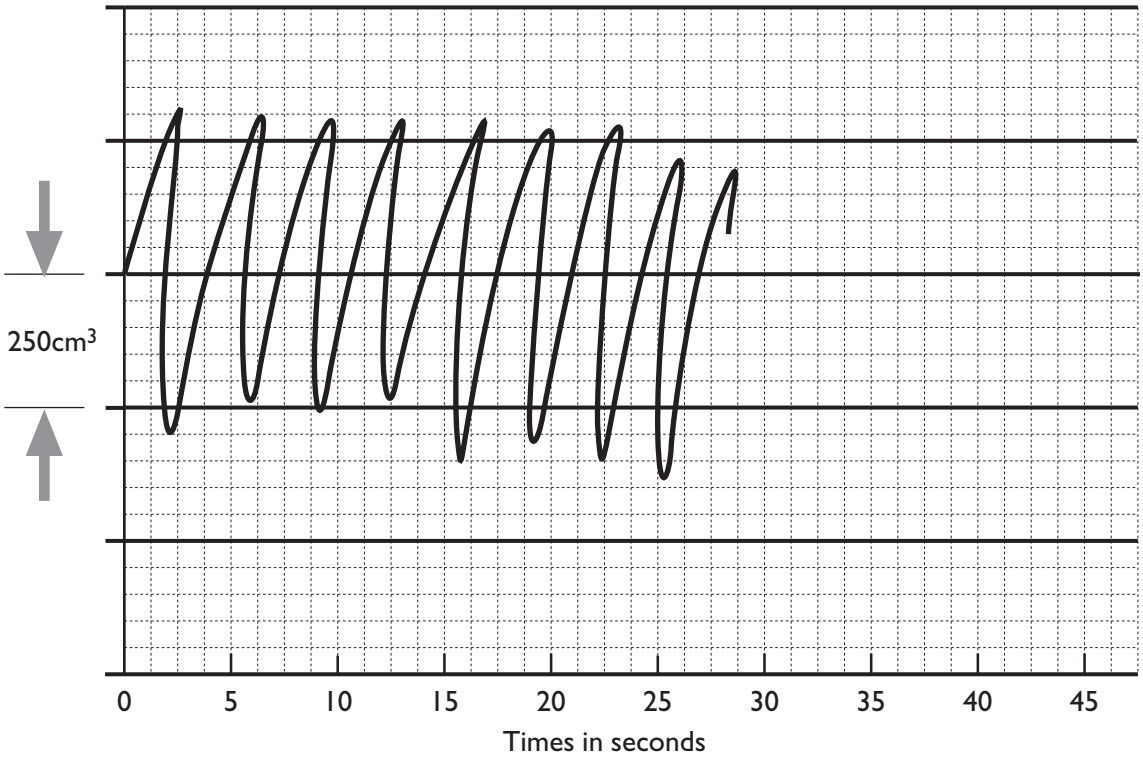
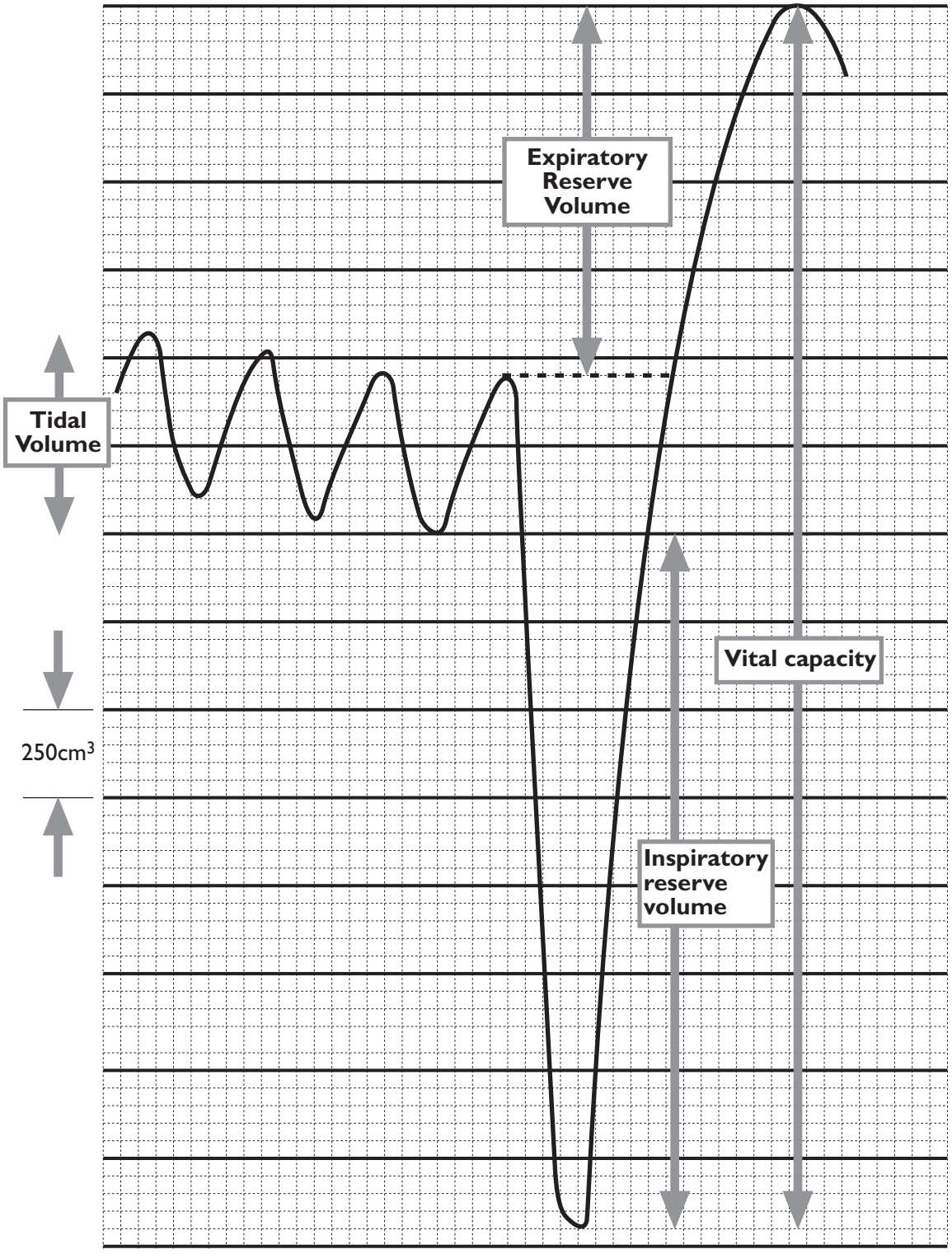


Figure 5: *Vital Capacity Trace. The vital capacity is determined by taking a maximum inspiration then exhaling as hard and completely as possible, this can also be referred to as the Forced Vital Capacity (FVC). The FEV1 is the percentage of the vital capacity exhaled in one second, normally about 85% in an adult. The maximum voluntary ventilation is the volume of air that can be breathed in 15 seconds of forced rapid and deep breathing multiplied by 4 to give a figure for one minute (in average adult males about 150 dm^3, and in average adult females about 95 dm^3). Indirect methods indicate that the total lung capacity is approximately six times the expiratory reserve volume.*



Spirometry and Exercise

Using a box spirometer whilst exercising poses limits on the type and duration of exercise that may be undertaken. Work on a treadmill, or more especially a cycle ergometer, is feasible as the subject can remain relatively still. A greater problem arises from the fact that the spirometer is a closed system and hence the volume of air/oxygen available to the subject is very limited under exercise conditions. The rate at which oxygen can be used during work can be high, therefore the air in the chamber may be replaced, either partially or entirely, with medical grade oxygen (medical grade oxygen must always be used, as industrial and laboratory grade cylinders are not continuously screened for dust content). Breathing pure oxygen for a short period of time should have no ill effects as any toxic effects only arise after 12-24 hours exposure. Nevertheless some workers have preferred to limit the oxygen in the breathing mixture to 60% or less. This clearly limits the duration of any exercise carried out, but it definitely errs on the side of safety.

Float Filled with Air

If the float is filled with air, and this is continually rebreathed, the amount of carbon dioxide (pCO_2) gradually increases as oxygen is absorbed by the subject and replaced by an equal volume of carbon dioxide. **This is potentially hazardous, and symptoms can develop within a couple of minutes.** As the level of carbon dioxide increases and the level of oxygen decreases, both the depth and rate of breathing increase, so that the ventilation rate (rate of breathing multiplied by the depth of breathing) may rise from about 10 dm^3 per minute to up to 50-60 dm^3 per minute. Heart rate and blood pressure rise, and mental confusion can set in.

Carbon Dioxide Absorption

If a carbon dioxide absorber is incorporated in the tube returning the exhaled air to the chamber ('Carbosorb' or 'Indicarb' or a similar grade of self indicating soda-lime granules must always be used, as there is an unacceptable risk of dust from lower grades), then the pCO_2 in the chamber will not rise, but the pO_2 (and the total volume of air) in the chamber will decrease. This is potentially hazardous. Although the lack of oxygen in the absence of carbon dioxide has little effect on the ventilation rate, the lack of oxygen could lead to loss of consciousness.

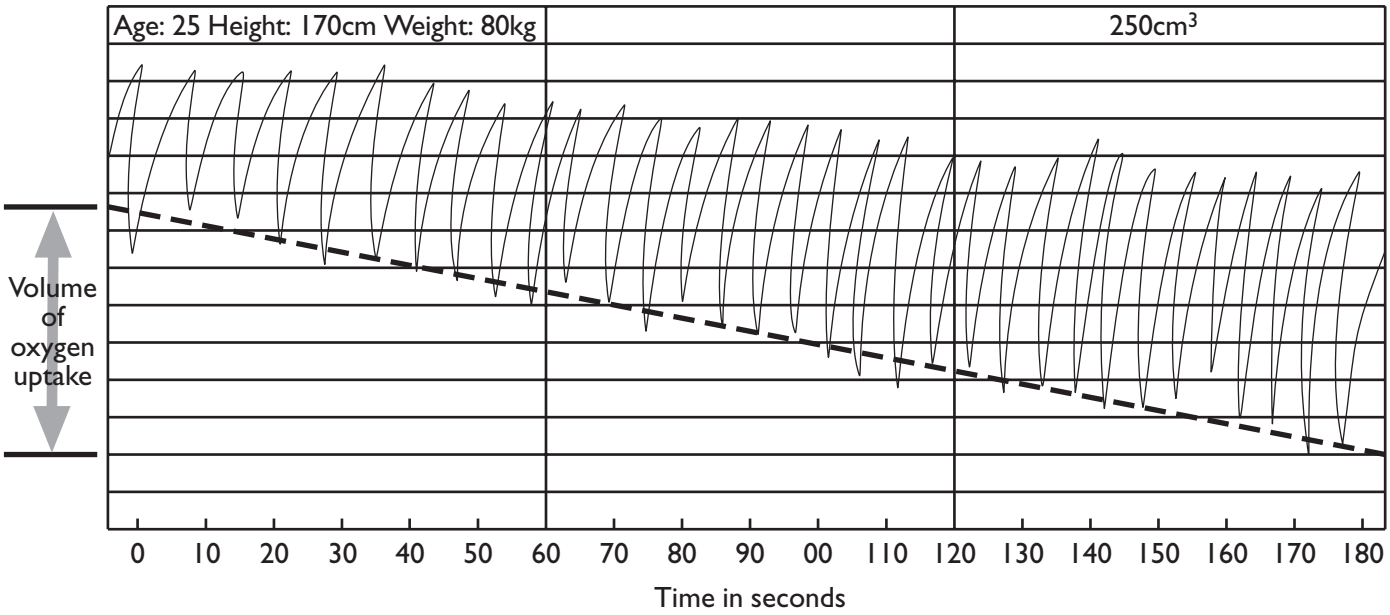
Float Filled with Oxygen

If the float is filled with oxygen, and a carbon dioxide absorber is incorporated in the tube returning exhaled gas to the chamber, the volume of oxygen in the chamber decreases in proportion to the volume of oxygen uptake by the subject. This investigation is less hazardous as the pCO_2 is not increasing, nor the pO_2 decreasing. However, all the oxygen can be used up, so a careful watch must be kept on the volume of oxygen left in the chamber as the experiment proceeds.

Length of Time on Spirometer

The question then arises of how long is it feasible for a subject to exercise while breathing the enclosed breathing mixture. This will be determined primarily by the severity of the exercise, the composition of the breathing mixture, and the body size of the subject. Direct measurements of oxygen uptake by college students under conditions varying from standing still to working to exhaustion show a range of values from around 200 cm^3 to over 4 dm^3 in each minute. Particularly large or well-trained individuals may have even higher minute-by-minute consumptions. It will be appreciated that, given a breathing mixture of 60% O_2, a large subject could undertake heavy exercise for only about 1 minute before exhausting the oxygen supply. Bearing this in mind it is possible to tailor experiments so that during the warm-up to the desired workload the subject might breathe room air (the spirometer lever would be set to 'atmosphere') only switching to the breathing mixture (lever set to 'spirometer') for the test period of 1-2 minutes. There is no reason why the oxygen in the spirometer cannot be topped up during the experiment provided the lever is moved to 'atmosphere' for the operation. The oxygen uptake trace would be interrupted but the test could at least be extended.

Figure 6: *Oxygen Consumption trace. With medical grade oxygen in the chamber and carbon dioxide absorber in the return tube. Oxygen consumption is usually expressed in dm^3 per minute.*



Measurement of Metabolic Rate from Spirometry

A useful 'spin-off' from oxygen uptake measurement is metabolic rate estimation. As the rate of oxygen consumption correlates directly with energy expenditure then it is possible to estimate metabolic rate under various test conditions. If one is willing to accept, and attempt to explain, the affects of a number of variables then worthwhile exercises can be devised to give students a broader understanding of energy input/output balance.

Resting Metabolic Rate

The average basal metabolic rate, expressed as oxygen uptake, is estimated to be 250 $cm^3 \cdot min^{-1}$. However, like many averages (heart rate, vital capacity, etc.) the above value is all but meaningless when applied to the individual. Not only do individuals differ widely in their basal energy expenditure but it is also extremely difficult to achieve the absolute minimum of body activity, especially when dealing with groups of students in a laboratory. However provided students are aware of the limitations this can still be a useful exercise.

The ideal conditions under which basal metabolism should be measured are:

a the subject should be lying down, or at least seated and relaxed;

b food should not have been eaten for 18-24 hours before the test;

c the external temperature should be about 20°C and should be the same for all the students tested.

At least two of these conditions (a and c) might give some difficulty, while (b) is almost impossible. The results obtained are most often higher than the 'average' due to students being unable to relax, or more likely to their just having eaten. If variations in body size are also taken into account it can be seen that a very wide range of results is to be expected.

Energy Cost of Exercise

Results can be used to calculate energy equivalents, ie. the amount of energy expended per unit volume of oxygen absorbed. The table below gives the energy yield in kilojoules for each dm^3 of oxygen absorbed at various Respiratory Exchange Ratios (RER) otherwise known as Respiratory Quotients (RQ) values. See Clegg, C. 'Exercise Physiology' page 53.

Table: *Energy yield in kilojoules for each dm^3 of oxygen absorbed at various RER(RQ) values.*

RER(RQ)	$kJ \cdot dm^{-3}$ O_2
0.70	19.62
0.75	19.84
0.80	20.10
0.85	20.36
0.90	20.61
0.95	20.87
1.00	21.13

If it is assumed that a typical resting RER is approximately 0.80 it can be seen that energy consumption at rest is 20.1 $kJ \cdot dm^{-3}$ oxygen. Hence if the oxygen uptake is measured at 250 $cm^3 \cdot min^{-1}$ then energy expenditure per hour would be:

$(0.25 \times 60)\ dm^3 \cdot hr^{-1} \times 20.1\ kj = 301.5\ kj \cdot hr^{-1}$

To work out the energy cost of exercise a similar principle can be applied. Note however that the RER value of 1.0 can only safely be assumed if the subject is working at, or very near to, his/her maximum aerobic power. Nonetheless assuming an RER of 1.0 and an oxygen uptake of 3.5 $dm^3 \cdot min^{-1}$, the energy equivalent of one hours work would be:

$(3.5 \times 60) \times 21.13\ kj \cdot hr^{-1} = 4437.3\ kj \cdot hr^{-1}$

1.3.2 Breath Volume Bags

The **Simple Breath Volume Bag** may be used to measure the vital capacity, and the tidal volume.

The **vital capacity** may be measured by taking the deepest possible breath in, and breathing out as hard as possible into a two metre long flat bag of transparent polythene, from which the air has been previously expelled. The bag is calibrated into tenths of a dm^3 (litre), with a maximum volume of just over 6 dm^3. The air in the bag is trapped by twisting the bag by the mouthpiece immediately after breathing out is finished, and pushed towards the closed end where it inflates the bag stiff. The volume of air in dm^3 can then be read off the scale on the bag. The **tidal volume** can be estimated by using a valved mouthpiece so air is breathed in normally from the atmosphere and out into the empty bag. This is repeated three times, the volume is measured, and the average tidal volume calculated for each breath.

The Douglas Bag This is much larger bag of about 120 dm^3, and can be used in conjunction with the valved mouthpiece. This allows expired air to be collected over a longer period of time, and gives more freedom of movement during exercise. As a result the minute volume and the tidal volume may be measured. The minute volume is calculated by recording the number of breaths, and volume of expired air over a five minute period, from which the volume of air breathed-in during one minute can be calculated. The tidal volume is calculated by dividing the minute volume by the number of breaths per minute. If samples of the exhaled air are taken from the bag and analysed for carbon dioxide and oxygen content, then the oxygen cost of a period of rest, and of a period of exercise, can be calculated, and from this the energy production, which is a measure of the metabolic rate.

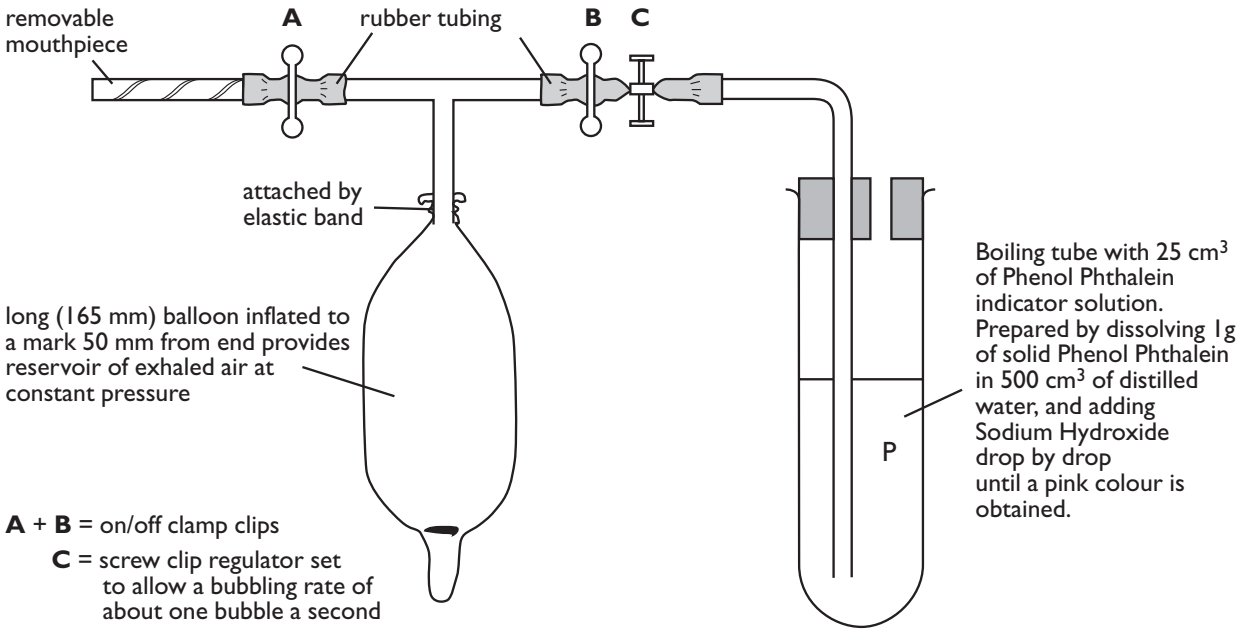
1.3.3 Pocket Spirometer or Microspirometer

These compact spirometers measure the rate at which air can be expelled from the lungs. They operate on the principle of the exhaled air rotating a precision turbine volume transducer, which converts (transduces) the number and speed of revolutions into a digital read out of various lung functions, namely; **Forced Vital Capacity** (FVC), **Forced Expiratory Volume in one second** (FEV1), and **Peak Expiratory Flow or Volume** (PEF or PEV) which is extrapolated from FEV1 values to give PEF or PEV in $dm^3\ min^{-1}$. The FEV1, and PEF or PEV are measures of air flow, which indicate the power of expiration and the resistance to air flow in the respiratory system, which in terms of lung function, are more significant than simply the quantity of air that can be moved in a single breath, ie the vital capacity.

1.3.4 Simple Apparatus to Determine the CO_2 Index

A simple apparatus can be constructed as shown in Figure 7.

Figure 7: *Simple apparatus to determine the CO_2 Index*


removable mouthpiece
A
rubber tubing
B
C
attached by elastic band
long (165 mm) balloon inflated to a mark 50 mm from end provides reservoir of exhaled air at constant pressure
A + B = on/off clamp clips
C = screw clip regulator set to allow a bubbling rate of about one bubble a second
P
Boiling tube with 25 cm3 of Phenol Phthalein indicator solution. Prepared by dissolving 1g of solid Phenol Phthalein in 500 cm3 of distilled water, and adding Sodium Hydroxide drop by drop until a pink colour is obtained.

The apparatus can be used to make simple comparative measures of CO_2 production before, during and after exercise. Samples can be taken at timed intervals throughout the investigation, without disrupting the procedure.

Method: Close tap **B** and open tap **A**.

Inflate the balloon in one breath up to the mark and close tap **A**.

Open tap **B** and allow air to bubble through the alkaline indicator solution (P). CO_2 being an 'acid' gas will neutralise the solution P. Count the bubbles and record the time for the pink colour to disappear.

The ratio:

$$\frac{\text{Time to decolour P at rest}}{\text{Time to decolour P after a period of exercise}} = CO_2 \text{ index}$$

Plot CO_2 Index and pulse rate against time on the same graph.

1.3.5 Stethograph

This consists of an expandable tube that fits around the chest and detects breathing movements. When linked to a recording system it can be used to measure ventilation rate and qualitative changes in tidal volume. The main advantage is that it does not require the use of a mouthpiece or nose clip, and so does not interfere with normal breathing.

1.4 Miscellaneous Measures

1.4.1 Body Fat

Skin fold callipers are used to measure skin fold thickness, which gives a measure of sub-cutaneous fat beneath the skin, and therefore a representation of total body fat. Measures are taken at four sites; triceps, biceps, sub-scapula (just below the shoulder blade), and anterior supra-iliac (just above the front of the pelvic girdle). Measurements are not very reliable as they vary significantly between measurers, and with their experience.

The measures can be used to give an estimate of % body fat, but as extrapolation to % body fat is neither valid nor reliable, the total figure for all the four sites in mm is increasingly quoted directly.

DONOGHUE, W. C. (1988) How to measure your % Body Fat: an instruction manual for the 'Slim Guide Skinfold Calliper'. Philip Harris.

DOUST, J. and BALE, P. (1992) Measuring Body Fat. National Coaching Foundation, 4 College Close, Beckett Park, Leeds. LS6 3QH.

1.4.2 Flexibility

A test of general flexibility is the sit and reach test, where the subject seated on the floor with their legs straight out in front of them, attempts to reach as far forward as possible on a measuring board.

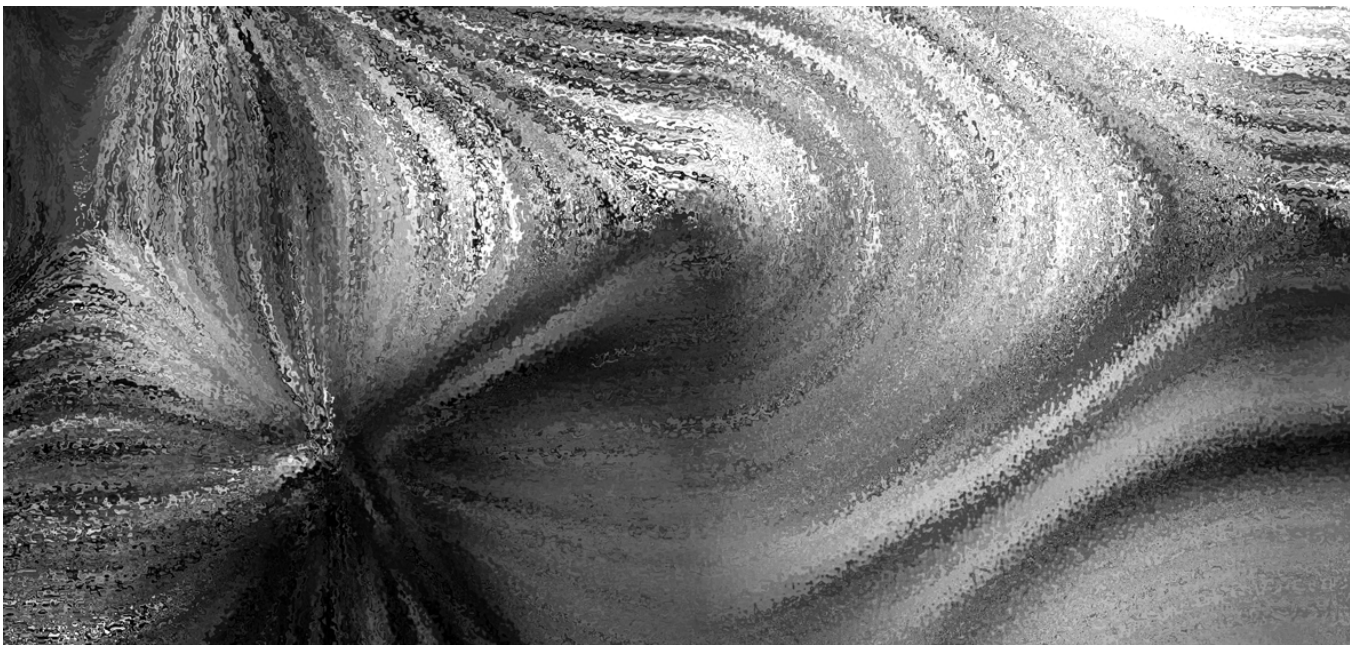
1.4.3 Strength

A crude measure of **'static strength'** is given by the grip test, which is taken as an indication of overall strength. An adjustable hand dynamometer is necessary as the force exerted is significantly affected by the fit of the hand around the apparatus. **'Trunk strength'** is estimated from the number of correctly executed sit ups performed in 30 seconds, and so-called **'functional strength'** or **'strength endurance'** is estimated from the time a bent arm hang can be maintained.

1.4.4 Balance, Agility, Co-ordination, and limb speed

A battery of simple tests can be devised for these measures, but tend to be less quantifiable, valid and reliable than the more physiological tests.

2 Testing of Physical Performance



2.1 Further Notes on the Use of Students in the Measurement and Testing of Physical Performance

Having established an understanding of the measurement of the heart rate and breathing, the response to exercise can be investigated; in particular that aspect known as cardio-respiratory endurance, which can be measured as aerobic capacity / maximal oxygen uptake / peak oxygen uptake / VO_2 max.

With sophisticated electronic equipment, continuous monitoring of subjects undertaking a wide range of activities in all types of conditions is possible. Without these however, methods of exercising at standard work rates in a controllable and reproducible way, which allow for simple monitoring, must be used. Such methods include; the **Step** test, the **Shuttle Run** test, **Treadmill** tests, and **Cycle Ergometer** tests.

Reasons for Testing

There are two possible reasons for putting subjects through rigorous physical exercise. One is simply to observe the way in which the body responds under physical stress, and the other is to provide a comparative measure from which a so-called 'fitness assessment' can be made. Any student having undertaken some strenuous routine will inevitably ask: 'does that mean I'm fit?'. Whilst being aware of the difficulties in defining 'fitness', a fitness assessment can provide a justification for the experiment, induce a higher degree of motivation in the student, and enable those who feel the need to set fitness targets.

Screening of Subjects

In suggesting some of these tests an assumption has been made that the participants will be healthy young adults in the post-16 age category, some of whom may be highly-trained and the others 'normal risk' subjects, that is free from chronic disease and not excessively elderly or infirm. It is also assumed that the subjects will be volunteers and that they have been asked to divulge, in confidence if necessary, any pertinent medical history. For instance, when testing an apparently fit 17-year-old it might be as well to know that s/he had open-heart surgery at the age of eleven. A comprehensive list of conditions which would exclude students from cardio-respiratory testing is published by the American College of Sports Medicine (ACSM) in their Guidelines for Exercise Testing and Prescription, Lea & Febiger, Philadelphia, 1991, p.59. The list concentrates on a range of cardiovascular disorders which would certainly exclude subjects from testing in the absence of close medical supervision and monitoring. However the list also includes other conditions more easily recognised and understood by the lay-person such as high resting diastolic blood pressure (over 120 mm Hg), acute infection, metabolic disease (e.g. diabetes mellitus), and muscular or skeletal injury or disorder that might be made worse by the test. In operating a catch-all, better-safe-than-sorry policy the author excludes anybody suffering from respiratory tract infections and who is taking any kind of medication for the condition. The question of what to do about asthmatics and those on long-term medication, for whatever reason, should really be referred to the subject's doctor.

Before the Test

Obtain Prior Informed Consent Forms (see p7). Reasons for terminating a test should be discussed and made clear; e.g. light-headedness and confusion (on the part of the subject that is!), any abnormal pain or discomfort, the wish of the subject to stop, and failure of any monitoring equipment. Subjects should be appraised of their rights in these matters before commencing the test and if necessary a system of hand signals be agreed with the tester.

The value of warm-up and warm-down procedures should be continually emphasised as students consistently ignore these components, often experiencing light-headedness and nausea.The very nature of some physical tests, especially maximal tests, mean that they cannot be repeated within a particular time period. It is therefore worthwhile to carefully check that all equipment is operating satisfactorily, and that the subject(s) fully understand(s) the test protocol before the test starts. Failure to make these checks may result in inordinate time-wasting and occasionally students failing to carry out the test properly and producing anomalous results.

Information that any student might like to keep on his/her fitness profile might also include resting heart rate. It is not possible to obtain this value in a classroom or laboratory, so students should be given instruction in taking their pulse rates as they wake in the morning. Taking this truly resting pulse on, say, four consecutive mornings and then taking a mean is a satisfactory method. Prior knowledge of maximum heart rate may also be of value.

Maximal Tests

Certain tests, such as the Shuttle Run are maximal tests, in which the subject performs maximum effort until exhaustion. In these maximal tests the motivation of the subjects under test may vary widely, and it is virtually impossible to determine when a 'maximum' effort is being made. Indications that an individual has reached his/her maximum include: a levelling-off of heart rate despite increasing workload (the heart rate might be expected to be in the range 180-190 bpm), and volitional exhaustion. In this latter case, question the subject routinely as to whether some factor other than cardio-respiratory limitation might have caused them to stop, for instance muscle pain.

A particular point of concern often expressed is whether maximal testing may be in some way dangerous. However, there is evidence (Pollock, Willmore, & Fox, 1978) that maximal tests carry no more risk than submaximal tests. Provided one is not dealing with high risk patients there would seem to be an extremely small risk as long as the guidelines are adhered to. Maintaining a sense of awareness and always supervising activities closely, along with thorough briefing of subjects/students are the essential practical steps.

Sub-Maximal Tests

Other tests, such as the Step Test are sub-maximal tests, and estimate maximum aerobic capacity or VO_2 max from sub-maximal performances. Such estimations or extrapolations depend on the fact that there is a direct linear relationship between the heart rate and oxygen consumption at various sub-maximal work intensities, so that VO_2 max can be estimated from sub-maximal rates at known work intensities. The same relationship exists between recovery heart rates and VO_2 max. There is a high correlation between the heart rate during sub-maximal exercise, and the heart rate 60 seconds to 90 seconds after exercise, in the same individual. In simple terms, the lower the exercise heart rate, and the shorter the recovery period, at a given work intensity, the greater the VO_2 max.

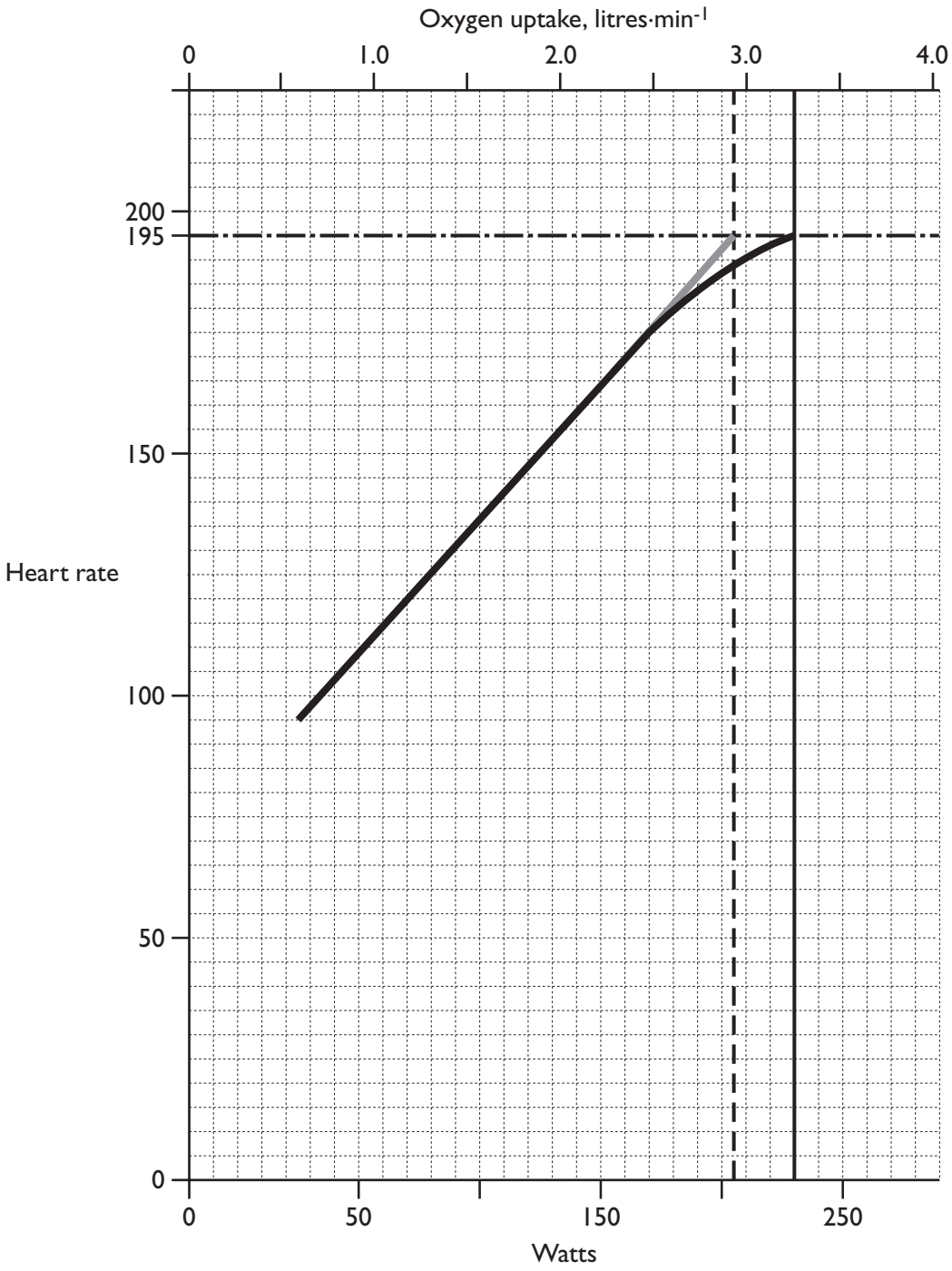
Estimation of Maximum Heart Rate

These estimations depend on assumptions. The commonly applied formula estimates maximum heart rate in beats per minute (bpm) at (220 - age in years), e.g. 195 bpm for 25 year olds; however, maximum heart rate varies by as much as +/- 10 beats between individuals of the same age, also in maximal tests carried out on eighty students in the 18-22 age range, most achieved heart rates of less than 190 bpm while only one exceeded 200 bpm. The conclusion would seem to be that if you wish to avoid over-estimating VO_2 max by as much as 20%, then it is best to 'underestimate' maximum heart rate by up to 10 bpm.

Maximum heart rate also decreases with age by about 10 beats per decade, and with a history of aerobic training, so that a fit 55 year old with a life time of endurance activity could have a maximum heart rate of only 160 bpm. Therefore allowance must be made for the decrease in maximum heart rate in these cases. If the maximum heart rate is overestimated, then so will be the maximum oxygen uptake.

Graphs, tables and nomograms are used for the purpose of predicting VO_2 max from sub-maximal heart rates at known work intensities, and recovery heart rates. (A nomogram is a system of graduated scales which allows for a value, in this case VO_2 max to be predicted, if the values on two other scales are known, in this case sub-maximal heart rate and work load.)

Figure 8: *Relationship between heart rate, work rate, and oxygen uptake. The linear relationship may be lost at very heavy work loads as the oxygen uptake may increase relatively more than the heart rate, therefore resulting in an underestimation of maximum aerobic power from sub-maximal performance. If the maximal heart rate is overestimated, as for example with older subjects, this will lead to an overestimation of the maximum aerobic power from sub-maximal performance. (After Astrand).*



In all types of tests, practice and training in the test procedure itself, can lead to dramatic, and specific improvements in test scores.

When different tests are used to estimate the same measure, such as VO_2 max, different results will be obtained due to the different size of the muscle groups being used, and other unknown influences. For example, on average, cycling produces a lower VO_2 max than when running uphill. These observations support the concept of Sport Specific tests, that is tests designed to measure physical performance under conditions as close to those of the specific sport as possible. So that cyclists would be tested on the cycle ergometer, rowers on rowing ergometers, swimmers in flumes, and runners on treadmills.(See Figure 11).

2.1.1 Health-Related Fitness Testing and Monitoring in Schools

A position statement on behalf of the Physical Education Association by its Fitness and Health Advisory Committee.

First published in the The British Journal of Physical Education. Volume 19, No. 4/5 July/October 1988.

Reprinted by permission of the Physical Education Association:

Introduction

The current emphasis on health-related fitness education and the increased availability of cheaper equipment and relevant computer software seems to have regenerated interest in field or performance tests of physical fitness. Many physical education departments are administering their own fitness test batteries and developing norm tables or percentile charts against which to compare their students. Some departments are including scores in student profiles and others are using them as a means of evaluating the effectiveness of their teaching programmes. Yet, there has been very little informed discussions about whether the use of health-related fitness tests with children is a worthwhile education experience.

Limitations of Testing

The quantitative assessment of children's physical fitness is one of the most complex problems in exercise science, and health-related fitness tests suitable for use in the school environment which provide highly valid and objective measures of exercise-induced fitness are currently not available. All performance tests (e.g. sit-ups, 12 minute run, flexed arm hang) are primarily dependent upon the subject's motivation to do well, and several of the more popular field tests are not even based on sound physiological foundations. Many of the data generated by these tests are therefore problematic, not capable of rigorous interpretation and more likely to cause confusion than solve problems or clarify health-related concepts.

The sensitivity of the components of health-related fitness to training is largely dependent upon genetic endowment. Furthermore, as each child grows and develops at his/her own particular rate, it is extremely difficult to separate the contributions of growth, maturation and exercise to any observed changes in performance. In any third year class of boys, 20% of the group may be pre-pubertal, 20% at puberty stage 5, and the rest somewhere in between. The use of norm tables, therefore, confounds the issue of relative fitness, as tables constructed on the basis of chronological age cannot logically be used to classify individual children at different levels of skeletal and biological maturation. The constant comparison of children on the basis of test scores will affect those who score low in a negative manner. These children will tend to use negative attributions (such as "I failed because I am no good") rather more than a more positive appraisal ("I may never be an Olympic Champion, but I am improving").

The advocates of fitness test batteries often assume that tests motivate individuals. There is no hard evidence to support this, and parallels in other areas of education would find supportive evidence only for those who do well.

Often those who need to exercise the most find least encouragement from such situations. The use of external rewards (e.g. badges) can be a legitimate motivational tool when used properly, but educational psychology research has demonstrated that long-term intrinsic motivation can be undermined by the use of external rewards. Incentive schemes should be used sparingly and only to encourage initial participation or to reward personal competence. The use of external rewards to bribe children to participate is likely to be counter-productive in encouraging lifetime participation.

Educational Issues

The monitoring of health-related fitness is only likely to be worthwhile if it is considered within the wider objectives of education and not judged in isolation as a means of assessment. One of the objectives of health-related fitness education is to bring about lasting changes in children by enhancing the affective, cognitive, motor and social skills necessary for lifetime involvement in physical activity. The priority is to develop a positive attitude towards fitness rather than a transient change in physiological status. Consequently, pupils need the skills to be able to participate independently of teacher guidance. They will only be able to do this if they have the necessary knowledge base. Testing and monitoring techniques may be valuable teaching aids in stimulating interest, introducing new concepts in health-related fitness and in helping children to learn about and understand their bodies.

Health-related fitness monitoring can be designed to encourage positive attributions and feelings of personal control of future behaviour. Adult involvement in exercise is related to feelings of physical competence or physical self-esteem. Fitness activities seem to be superior to other physical education activities in self-esteem development. If health-related fitness testing and monitoring emphasises personal involvement and improvement rather than social comparison it can make a positive contribution to physical self-esteem and therefore subsequently to a lifetime commitment to exercise.

Conclusion

It is therefore the view of the Physical Education Association that fitness testing and monitoring can be valuable components of a health-related fitness programmes if they are used:

i *to encourage positive attitudes towards health-related fitness;*

ii *to increase understanding of the principles of health-related fitness;*

iii *to promote a lifetime commitment to health-related fitness.*

However, teachers and students must be aware of the severe limitations of field tests in the complex analysis, assessment and classification of children's fitness.

References for this Article

ARMSTRONG, N. (1986). A comment on physical fitness testing. British Journal of Physical Education, 17 (1), 34.

ARMSTRONG, N. (1987). A critique of physical fitness testing. In S. J. H. Biddle (ed.). Foundations of health-related fitness in physical education. London: Ling Publishing. 136-138.

ARMSTRONG, N. (1986). What does fitness testing really test? Education and Health, 4 (4), 87-88.

BIDDLE, S. J. H. (1986). Field tests of health-related fitness. British Journal of Physical Education, 17 (1), 31-33.

BIDDLE, S. J. H. and FOX, K. R. (1987) A guide to health-related fitness testing. In S. J. H. Biddle (ed). Foundations of health-related fitness in physical education. London: Ling Publishing, 127-135.

FOX, K. R. and BIDDLE, S. J. H. (1986). Health-related fitness testing in schools I - introduction and problems of interpretation. Bulletins of Physical Education, 22 (3), 54-64.

FOX, K. R. and BIDDLE, S. J. H. (1987). Health-related fitness testing in schools II - philosophical and psychological implications. Bulletins of Physical Education, 23 (1), 28-39.

2.1.2 General References

ASE. Safeguards in the School Laboratory (9th Edition). (1988). ASE, College Lane, Hatfield, Hertfordshire. AL10 9AA.

BURKE, E. J. and MICHAEL, E. D. (1990). Laboratory Experiences in Exercise Physiology. Second Edition. Mouvement Publications (1993).

CLEAPS, The CLEAPS Laboratory Handbook, School Science Service, Brunel University, Uxbridge UB8 3PM.

Council of Europe. Committee for the Development of Sport. EUROFIT (1993). Handbook for the EUROFIT tests of physical fitness. Distributed in the UK by: The Sports Council, 16 Upper Woburn Place, London. WC1H 0QP.

EVERETT, K. & JENKINS, E. W. A. (1991). Safety Handbook for Science Teachers - 4th Edition. John Murray.

HODGSON, J. & TINGLE, J. (1988). Your Legal Position in Teaching. New Education Press.

MEDICAL RESEARCH COUNCIL. (1991). The Ethical Conduct of Research on Children. Medical Research Council Ethics Series. Publications Group, 20 Park Crescent, London. W1N 4AL.

THE NATIONAL COACHING FOUNDATION. (1986). Safety First for Coaches: Coaching Handbook Two. N.C.F., 4 College Close, Beckett Park. LS6 3QH.

2.2 Step Test

This involves stepping up and down a measured height at a controlled rhythm, requires the minimum of apparatus and space, and can be administered to large numbers at the same time. The stepping height can be adjusted for individuals, for example from between 10 cm and 50 cm, depending upon the height and weight of the subject. The stepping rhythm is established with the aid of a pre-recorded signal, of so many steps per minute (22 for females and 24 for males). There is always the risk of stumbling, so care must be taken. Due to the stepping action it is not easy to monitor the blood pressure and breathing volumes continuously, without electronic monitors, but it is possible to monitor the pulse rate as described previously.

The pulse rate can be taken before, during and after a standard stepping period (usually 3 minutes). Once the heart rate has returned to its pre-exercise resting rate, the work period can be repeated if necessary with increased effort, for example by increasing the mass with added weights, and/or the rate of stepping. The data recorded on the exercise, and post-exercise recovery heart rates, can be used for the indirect estimation of maximum oxygen uptake per minute or VO_2 max.

Step tests are theoretically as valid (they should measure what they claim to measure) and reliable (they should do so consistently) as cycle ergometer tests in estimating VO_2 max from sub-maximal heart rates. However, they rely on doing work by raising the body weight against gravity at a set rate, and their validity and reliability depends on correct stepping technique which is difficult to maintain. Any change in the height due to poor leg extension, or in the rate of stepping during a test, will change the work rate, usually reducing it, and this will invalidate the results. In this way step tests tend to give significantly greater scores for VO_2 max than tests performed on the cycle ergometer. Stepping efficiency is also affected by the length and proportions of the legs. Therefore the VO_2 max predictions from sub-maximal heart rates are best done on a cycle ergometer.

Score Classification for Harvard Step Test

Fitness category	Score *(Boys & Girls)*
Very poor	below 55
Poor	56 – 64
Average	65 – 79
Good	80 – 89
Excellent	90 or above

SYKES, K. (1987) Fitech Step Test. Fitech Ltd. Alan House, 17-19 Boughton Road, Chester, CH3 5AE.

Also see: HEYWARD, V. H. (1991) Advanced Fitness Assessment and Exercise Prescription. Human Kinetics Books, Champaign, Illinois.

2.3 Shuttle Run Test

MULTISTAGE FITNESS TEST
Table of Predicted Maximum Oxygen Uptake Values
Department of Physical Education and Sports Science Loughborough University

Level	Shuttle	Predicted VO_2 Max
12	6	55.4
Average runner should run 10k *(6.2 miles)* **in about 42 minutes**		

Level	Shuttle	Predicted VO_2 Max
19	6	79.2
Probable maximum for females		

Level	Shuttle	Predicted VO_2 Max
21	16	88.2
Close to maximum for male Chris Boardman, cyclist World record holder *(1997)*		

The Endurance Shuttle Run (ESR) test is a simple test which provides valid and reliable estimates of the maximum oxygen uptake or VO_2 max.

The subject runs up and down (shuttles) a 20 metre track, trying to keep in time with a series of audio signals from a pre-recorded audio cassette (the common name for this test being the 'bleep test'). Initially the running speeds are very slow, but the interval between signals decreases in a series of 'levels', each of which lasts about one minute, and the running speed must increase accordingly. The test is progressive and maximal, ending when the subject can no longer keep up with the signals.

The level, and the number of shuttles into that level, at which the subject drops out, approximates to a predicted VO_2 max which can be derived from a table supplied in the instructions. So for instance if a subject stopped after the eighth shuttle at level 7, it can be seen from the table that this equates to a VO_2 max of 39.2 $cm^3 \cdot kg^{-1} \cdot min^{-1}$.

(A measure of 'running speed agility' may also be derived from another version known as the Speed Shuttle Run (SSR). In this, the time taken to run five 'to and fros' is recorded.)

BREWER, J., RAMSBOTTOM, R. and WILLIAMS, C. (1988) Multistage Fitness Test. A progressive shuttle run test for the prediction of maximum oxygen uptake. National Coaching Foundation, 4 College Close, Beckett Park, Leeds. LS6 3QH.

2.4 A Maximal Treadmill Test

A number of protocols exist aimed at individuals who differ in terms of health and fitness, most of which use tilting treadmills. In a progressive multistage test the workload can be increased by increasing the inclination of the track. However tilting treadmills are more expensive than level ones, so what follows is a suggested way of using a level treadmill.

As with all protocols the important factors are: the health/fitness status of the subject, the length of time that the test should reasonably take, the starting level, the size of the workload increments, the time spent at each level, and the overall duration of the test. Heart rate is monitored throughout, by whatever means is available. If an electronic HRM is being used it may be necessary to suppress the treadmill motor to avoid interference.

There should be a gentle warm-up before each test.

A starting level for non-trained subjects could be:

2.5 mph, with a **Workload increment** of 1.5 mph, and 2 minutesat each level, with an **overall duration** of up to 15 minutes. This may be varied depending on the degree of fitness of the subject. For those who admit to being in poor shape it is feasible to either reduce the workload increment to, say 1 mph, or to extend the time at each level. For highly trained subjects the workload increments can be increased. The guideline is that the subject attains maximum aerobic work within a reasonable time period.

The following graphs show the volume of O_2 uptake (VO_2) and heart rate traces of

i a highly trained elite middle distance runner (Figure 9);

ii a highly trained professional rugby forward (Figure 10); and,

iii the two heart rates compared (Figure 11),

★ **Note the different scales on the vertical axis.**
In this instance VO_2 was being measured directly by gas analysis.

The table shows the relationship between level running speed and VO_2 using the predictive equation from the American College of Sports Medicine (ACSM): Guidelines for Exercise Testing and Prescription, Lea & Febiger, Philadelphia, 1991, pp.296-297.

Table *Conversion table for level treadmill running:*

Speed (mph)	METs	VO_2($cm^3 \cdot kg^{-1} \cdot min^{-1}$)
1	2.53	8.86
2	4.06	14.21
3	5.59	19.57
4	7.12	24.92
5	8.65	30.28
6	10.19	35.67
7	11.72	41.02
8	13.25	46.38
9	14.78	51.73
10	16.31	57.09
11	17.84	62.44
12	19.38	67.83
13	20.91	73.19
14	22.49	78.54
15	23.97	83.90

NB. *The resting component is given as 3.5 $cm^3 \cdot kg^{-1} \cdot min^{-1}$. This is meant to be equivalent to the resting oxygen consumption, and is also described as 1 MET, or Metabolic Equivalent. METs may be used to determine the increments between stages in a multistage test.*

Figure 9: *Graph to show heart rate and oxygen uptake of a middle distance runner performing a maximal treadmill test.*

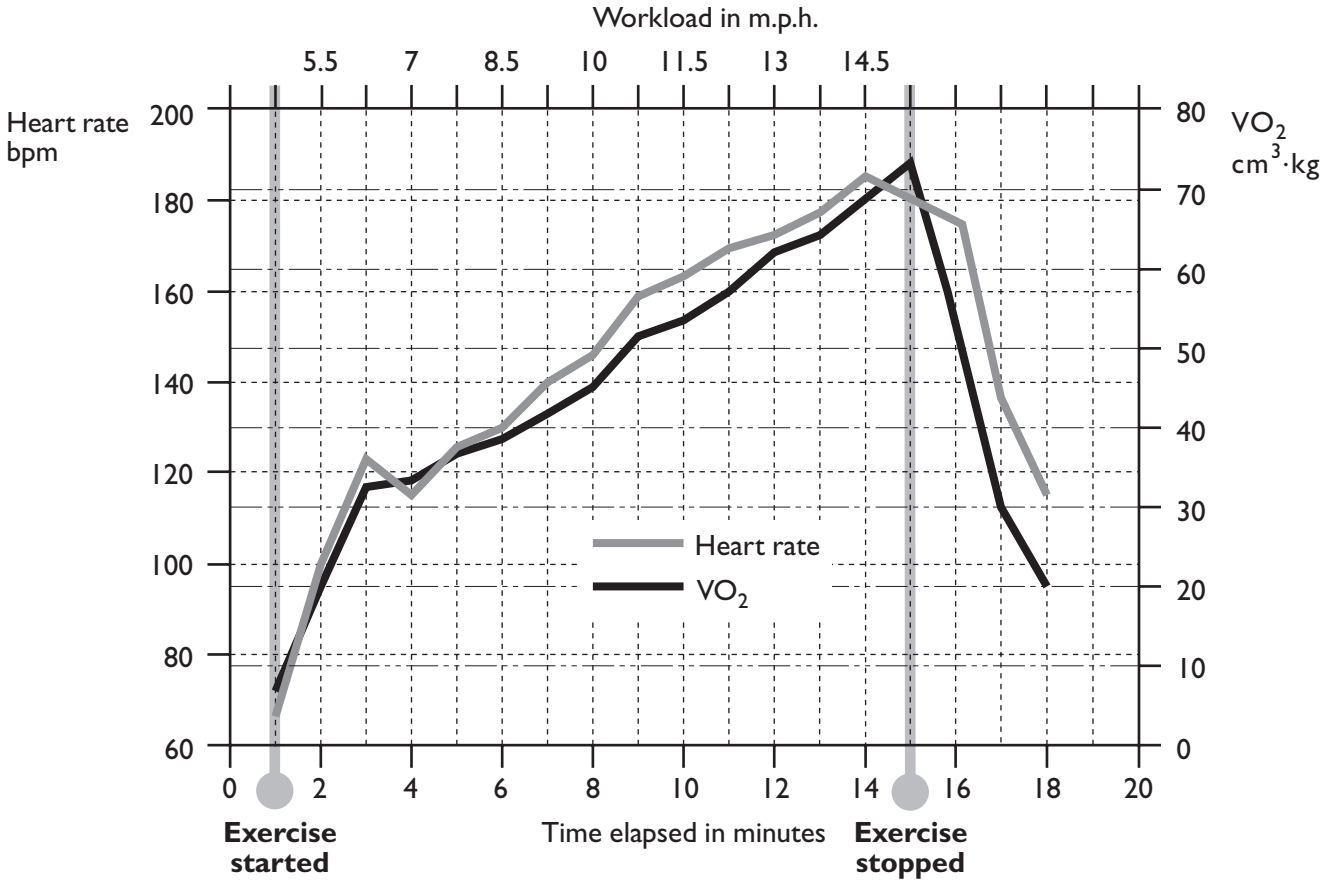


Figure 10: *Graph to show heart rate and oxygen uptake of a rugby forward performing a maximal treadmill test.*

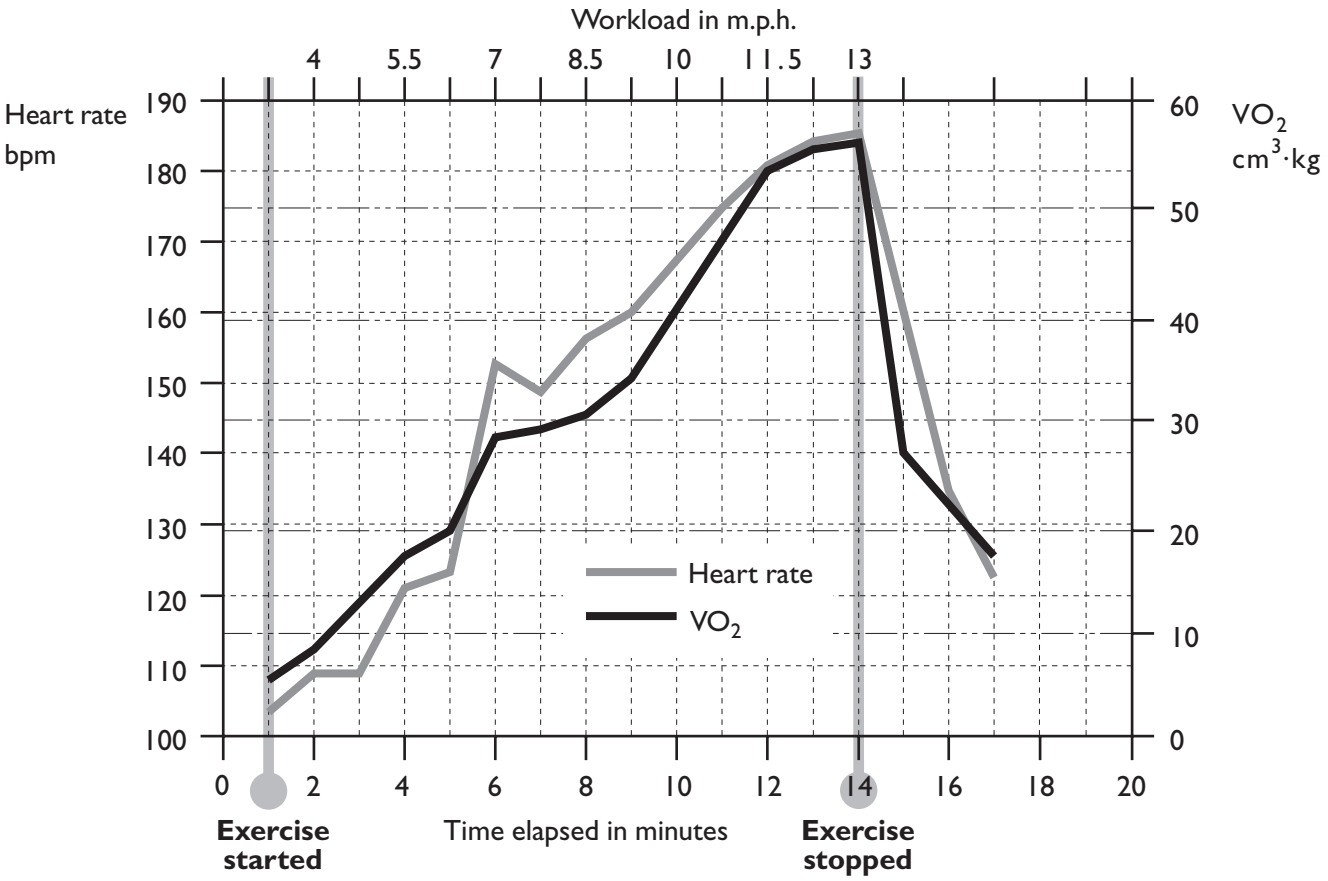
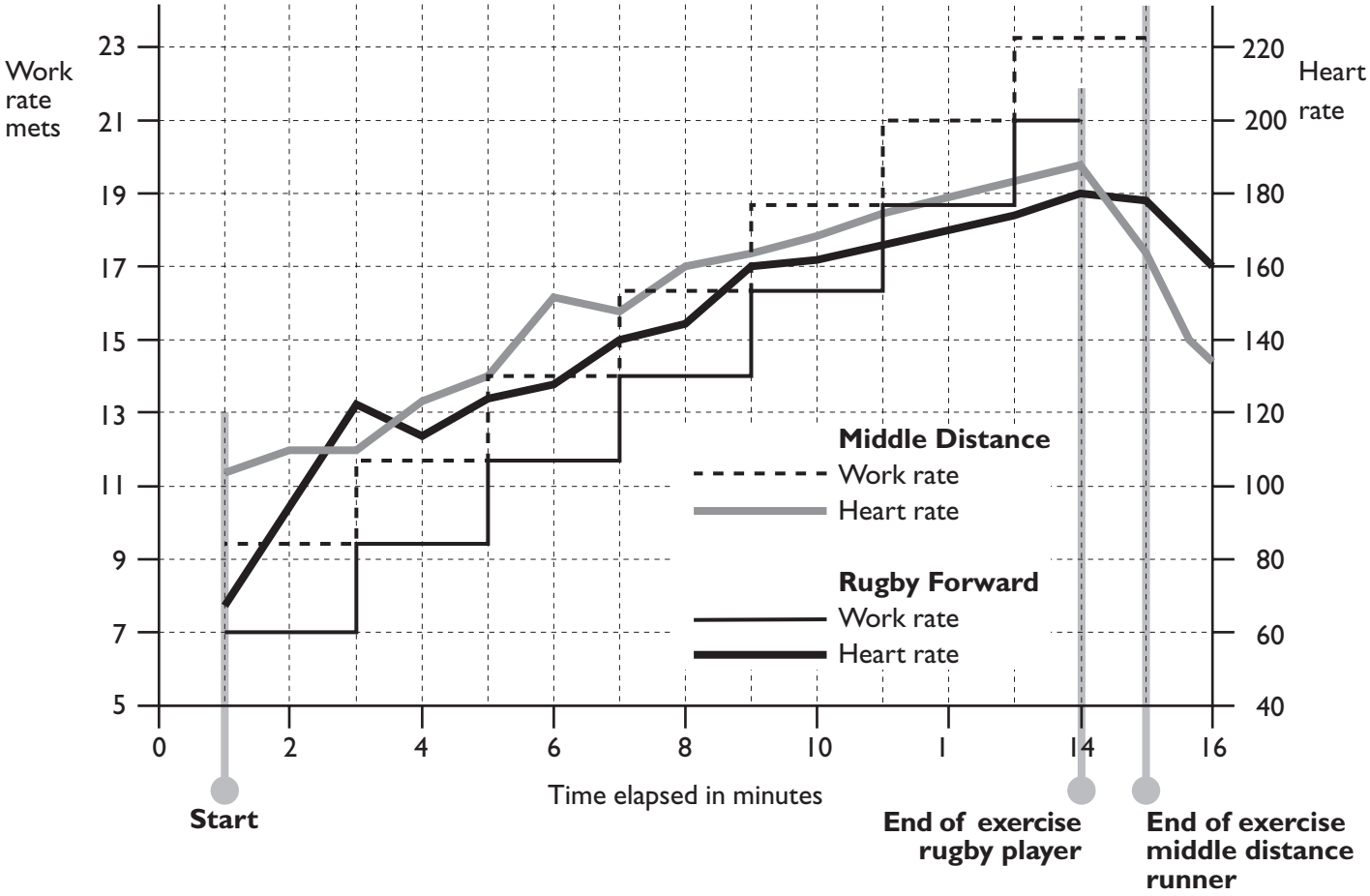


Figure 11: Graph to show comparison of heart rates of a middle distance runner and a rugby forward performing maximal treadmill tests.

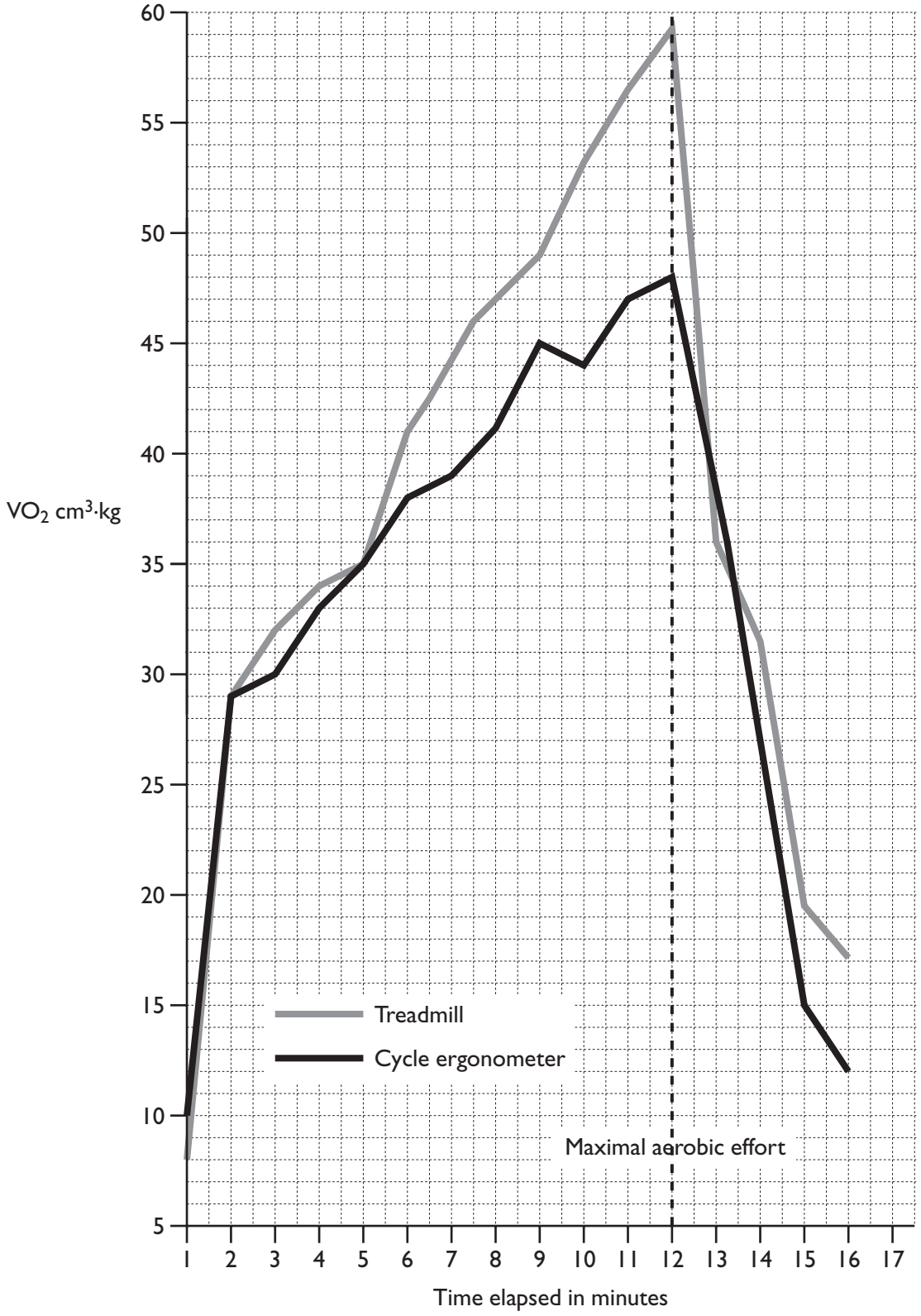


2.5 Cycle Ergometer

This is a static exercise cycle with weight loaded resistance on the front wheel, so that power output is directly related to the frictional resistance and rate of pedalling. Sub-maximal rates of pedalling can be established by means of a signal of some sort. Choice of rate is important as different rates of pedalling have differing mechanical efficiencies, although between 50 and 70 revs per minute (rpm) the efficiency is fairly constant. Otherwise pedalling rate can be maximal if necessary. The relatively still upper body allows greater ease of measuring changes in heart rate, breathing rate, etc., than is possible for example with step tests.

One drawback with cycle ergometer testing is that subjects who are unused to cycling may under-perform due to poor mechanical efficiency while pedalling, particularly at higher workloads. This raises questions about the validity of such tests, and it is a factor to bear in mind. Many students require guidance as to the appropriate saddle height (they invariably set it too low) and handlebar position (too far forward) for most efficient working. The graph below (Figure 12) illustrates this effect. The same subject performed both a treadmill and a cycle ergometer test. It can be seen that the lines diverge as the workload increases. Poor technique would seem to be a factor in the underachievement on the cycle ergometer. Furthermore, as the aerobic capacity is determined not only by the efficiency of the cardio-respiratory system, but also by the aerobic efficiency of the muscles involved, estimates of the subject's VO_2 max will vary according to the muscles involved in the test.

Figure 12: *Graph of O_2 uptake against time in a single subject during a progressive maximal test on (i) a treadmill, and (ii) a cycle ergometer.*



Tests carried out using a cycle ergometer include those based on: the **heart rate**, the **energy output**, and the **power output**.

2.5.1. Heart Rate Measures Whilst Using the Cycle Ergometer

VO_2 max may be predicted from sub-maximal and recovery heart rates, as with the step test. However, the cycle ergometer provides more valid and reliable results than the step test, since the work is controlled more effectively.

If samples of expired air are collected at intervals throughout a continuous progressive work loading, and analysed, more direct measurement of oxygen consumption can be obtained. However, these direct techniques require first class equipment and experienced personnel, and even then can show variations in calculations of VO_2 max by as much as 25%.

I Physical Working Capacity at 170 BPM. (PWC_{170})

This provides a measure of sub-maximal aerobic power.

The subject pedals continuously for 9 minutes, during which time the workload is increased at 3 minutes and 6 minutes. The heart rate is measured during the last 15 seconds of each of the three loadings. The loads are increased so that the heart rate approaches 170 bpm at the end of the test. A suggested initial workload for the PWC_{170} test is 50 watts for women and 100 watts for men. The workload increment is 25 watts unless at the end of the first time period the heart rate has not reached 110 bpm. In this case the increment should be 50 watts, then 25 watts thereafter until the heart rate reaches 170 bpm. The workload corresponding to a heart rate of 170 bpm (PWC_{170}) can then be calculated, and expressed in watts per kg. body weight. The fitter the subject the greater will be the PWC_{170}. The PWC_{170} has been found to correlate well with measures of VO_2 max with an error of $\pm$10%. It has been estimated that the VO_2 max is from about 20-27% more than the oxygen uptake at a heart rate of 170 bpm. (Remember that mature subjects with a long history of endurance training may have a maximum heart rate below 170 bpm).

II A Submaximal Cycle Ergometer Test

This test assumes a linear relationship between workload, heart rate, and O_2 uptake (VO_2).

The subject exercises at three levels of sub-maximal work, and the heart rate is measured at each level.

It is important that the subject should work at a given level for a period of time long enough to allow the heart rate to have reached a 'steady state' before the workload is increased. In this way a heart rate which is most closely related to the amount of work being done at that level can be determined.

The Test

Pedal cadence: 50 rpm throughout.

Initial workload: 25 watts (150 kg·m·min^{-1}).

Time period at each level: 3 minutes (*measure heart rate at the end of minutes 2 and 3 at each level).

This should be long enough for the heart rate to have reached a steady level. If, however, the heart rate value at the end of the third minute is more than five beats greater than the value at the end of the second minute, this means that the rate is still rising, and another minute should be allowed at this level.

Workload increments: The amount by which the workload is increased between levels 1 and 2 depends upon the heart rate achieved at level 1. As a guide, it the heart rate at minute 3 of level 1 is:

- less than 80 bpm; increase the load to 125 watts (750 kg·m·min^{-1})
- 80–90 bpm; increase the load to 100 watts (600 kg·m·min^{-1})
- 90-100 bpm; increase the load to 75 watts (450 kg·m·min^{-1})
- greater than 100 bpm; increase the load to 50 watts (300 kg·m·min^{-1})

The aim being to raise the heart rate to at least 110 bpm at level 2, as it is only above 110 bpm that a linear relationship exists between workload, heart rate, and oxygen consumption.

At all subsequent levels the workload can increase regularly by 25 watts (150 kg·m·min^{-1})

Number of levels: 3 or 4; remember this is a sub-maximal test, and for young fit adults the heart rate should not rise above 170 bpm.

The Results: having gathered data relating heart rate to workload, there are two possible uses for the data. Firstly, by plotting the line of heart rate against work (at least 3 points should be plotted) and then extrapolating that line to the predicted maximum heart rate, a predicted maximum

physical work capacity (PWC) can be determined. In plotting such a line, ignore the heart rate value for level 1, as this is likely to be below 110 bpm, which is the value above which a linear relationship exists. Secondly, the data can be used in conjunction with a nomogram which relates heart rate at a particular workload to maximum aerobic capacity (VO_2 max). Such a nomogram is attributed to Astrand (1960) and can be found in **Astrand, P-O, and Rodahl, K. Textbook of Work Physiology, (1977), 2nd edition, McGraw-Hill**.

Reference: Golding, L. A., Myers, C. R., Sinning, W. E. Y's Way to Physical Fitness, (1989), 3rd edition, YMCA of the USA.

III A Maximal Cycle Ergometer Test

Cycle ergometers are generally available in two basic types: those which employ a weighted flywheel to create resistance (Monark, Tunturi) and those which use an electromagnetic braking force (Cateye). The latter type are widely used in gymnasia and fitness suites as they are 'user-friendly' and often can be programmed to input heart rate data and set target workloads. Modern cycle ergometers, of whichever type, have LCD display screens showing at least pedal cadence (rpm) and work rate (watts). Most bicycle tests use a pedalling frequency of 50 or 60 rpm, although Hermansen & Saltin (1969) found that 60 rpm produces a higher VO_2 max than 50, 70, or 80 rpm. The protocol that follows is for the type of ergometer which has a disc loading weight basket to vary the resistance. (Note that provided the resistance can be varied by known, regular increments, and resistance can be correlated with power in watts for a particular pedal speed, then the protocol can be adapted for a range of ergometers.)

The protocol is based on that of McArdle et al. (1973)

Pedal cadence: 60 rpm throughout.
Initial workload: 90 watts.
Workload increments: 30 watts.*
Time period at each stage (level): 2 minutes.

* *(The means by which the loading may be increased depends upon the type of cycle ergometer. With the disc-loading type a specific weight must be added to the flywheel: the electromagnetic types have a range of predetermined selectable resistances. Reference must be made to the manufacturer's handbook to determine the number of watts each loading level equates to at 60 rpm.)*

To calculate VO_2 max from the results of the test, record the maximum workload achieved before exhaustion. Then substitute values into the ACSM equation.

$$VO_2\ \text{cm}^3\cdot\text{min}^{-1} = \underbrace{\text{kg}\cdot\text{m}\cdot\text{min}^{-1}* \times 2\ \text{cm}^3\cdot\text{min}^{-1}}_{\text{resistive component}} + \underbrace{3.5\ \text{cm}^3\cdot\text{kg}^{-1}\cdot\text{min}^{-1} \times \text{BW (kg)}}_{\text{resting component}}$$

*This is the workload (6 $\text{kg}\cdot\text{m}\cdot\text{min}^{-1}$ = 1 watt).

Worked example: consider that a 70 kg individual achieves 210 watts before exhaustion, then:

$$\text{Resistive component} = (210 \times 6) \times 2 = 2520\ \text{cm}^3\cdot\text{min}^{-1}$$

$$VO_2\ \text{max} = 2520\ \text{cm}^3\cdot\text{min}^{-1} + (3.5\ \text{cm}^3\cdot\text{kg}^{-1}\cdot\text{min}^{-1} \times 70\ \text{kg})$$

$$= 2520\ \text{cm}^3\cdot\text{min}^{-1} + 245\ \text{cm}^3\cdot\text{min}^{-1}$$

$$= 2765\ \text{cm}^3\cdot\text{min}^{-1}$$

$$= 39.5\ \text{cm}^3\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$$

2.5.2 Energy Output

This can be calculated from the formula:

energy output in Joules = force × Distance.

With a cycle ergometer the:
force in newtons (N) is calculated from the mass of the load in kilograms by multiplying by 10 (as the weight of one kilogram mass is 10N), and the:
distance in metres is recorded from the 'mileometer' (odometer) or by multiplying the circumference of the wheel by the number of revolutions in a given time.

2.5.3 Power Output

This can be calculated from the formula:

$$\text{Power in Watts} = \frac{\text{Energy output in Joules}}{\text{Time in seconds}}$$

If intermediate or continuous readings can be taken then a power profile can be obtained for the complete exercise period.

The Wingate Test

After a warm-up period the subject pedals flat out for 30 seconds against a resistance related to body weight, age and sex, and the power profile is recorded and plotted against time. The **maximum anaerobic power** is usually reached after about 5 seconds, and is generated by the **alactic anaerobic** ATP/PC system.

Over the 30 second period of flat out effort there is a progressive depletion of the alactic anaerobic ATP/PC system, and an increasing involvement of the lactic anaerobic system. Because of the overlapping involvement of the anaerobic systems they cannot be clearly separated, but the average power over the 30 second period of exercise is taken as an indicator of the **lactic anaerobic power** which is calculated per kilogram of body mass. However, it must be remembered that 30 seconds will not exhaust the anaerobic capacity, an alactic component is also involved, and about 20% of the total energy production during a 30 second Wingate Test is aerobic.

It is important during the warm-up that subjects perform several flat-out sprints to establish a state of readiness and to ensure that they are aware of the 'feel' of the effort involved. Failure to practice in this way often leads to the initial effort being restricted, so that when the subject realises s/he kicks harder towards the end. This means that peak anaerobic power is reached later than anticipated and the extent of power decline is less than it might otherwise be.

The loading level for the Wingate test should vary according to body weight and gender. For males the body weight in kg. can be multiplied by 0.083 – 0.092 to give the mass in kg added to the flywheel. For females multiply the body weight by 0.075.

During the test, watts should be recorded at 5 second intervals so that power decline can be plotted against time. This will help to check that the test was carried out properly. If it was, there should be a smooth steady decline after an early peak. Any change in the rate of decline might mean that the subject has either checked or increased his/her effort during the test which will affect the end result.

Warm-down is paramount after this test. Individuals who do not warm-down often complain of giddiness and nausea.

If the oxygen uptake during the period of exercise can be measured, then the oxygen deficit can be calculated, and used to determine the **anaerobic energy yield**.

The progressive power decline can be calculated from the formula:

$$\text{Power decline} = \frac{\text{Peak power} - \text{End power}}{\text{Peak power}} \times 100$$

The **power decline** is a measure of fatigue and can be used to calculate a **fatigue index**, using the formula:

$$\text{Fatigue index} = \frac{\text{Power decline}}{\text{Time between peak and end power in seconds}}$$

A repeat test five minutes later, can give a measure of the repeat capacity, important to games players.

2.6 Additional Power Tests

2.6.1 Sargent Vertical Jump

This measures the difference (*J*) between the subject's standing reach, and their maximum jump and reach height. The jumping technique is standardised, and at least three attempts are allowed for the perfection of the technique. It is a measure of leg power, although no account is taken of the subject's weight.

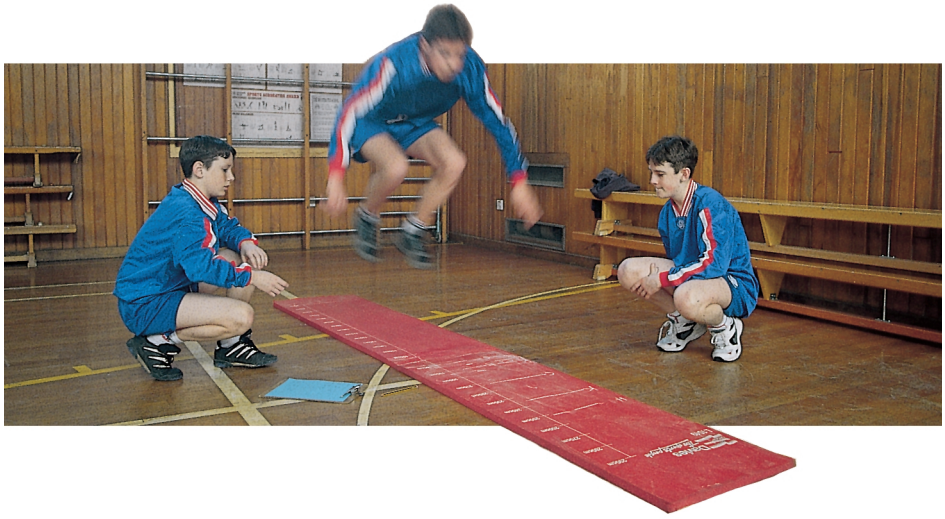
The **alactic power output** can be calculated from the expression:

$$\text{Alactic power output} = 2.2 \times \text{Body weight in kg} \times \sqrt{J}$$

2.6.2 Standing Long Jump

This measures the distance jumped from a standing position.

In the Standing Long Jump test the distance that can be jumped from a standing two footed take off is measured, this is taken as a measure of explosive leg strength or power. A person's height can affect the distance jumped. This can be allowed for by first marking their height on the mat, and measuring the distance jumped in relation to this. No account is taken of the subject's weight, which also will affect the distance jumped.



2.6.3 Margaria-Kalamen Stair Test

This measures the time taken to sprint up a number of steps as fast as possible. The time must be measured precisely, usually by using two switch mats connected to a time recorder (sensitive to 0.01s) or two photo cells and an electronic timer. The time taken to raise the body mass through a certain vertical height gives a measure of the **power output**. Usually the subject stands 6 m in front of the staircase (with steps 175mm high), and runs up the stairs as fast as possible 3 steps at a time. Switch mats being placed on the 3rd and 6th stair. **Power output** can be derived by using the formula:

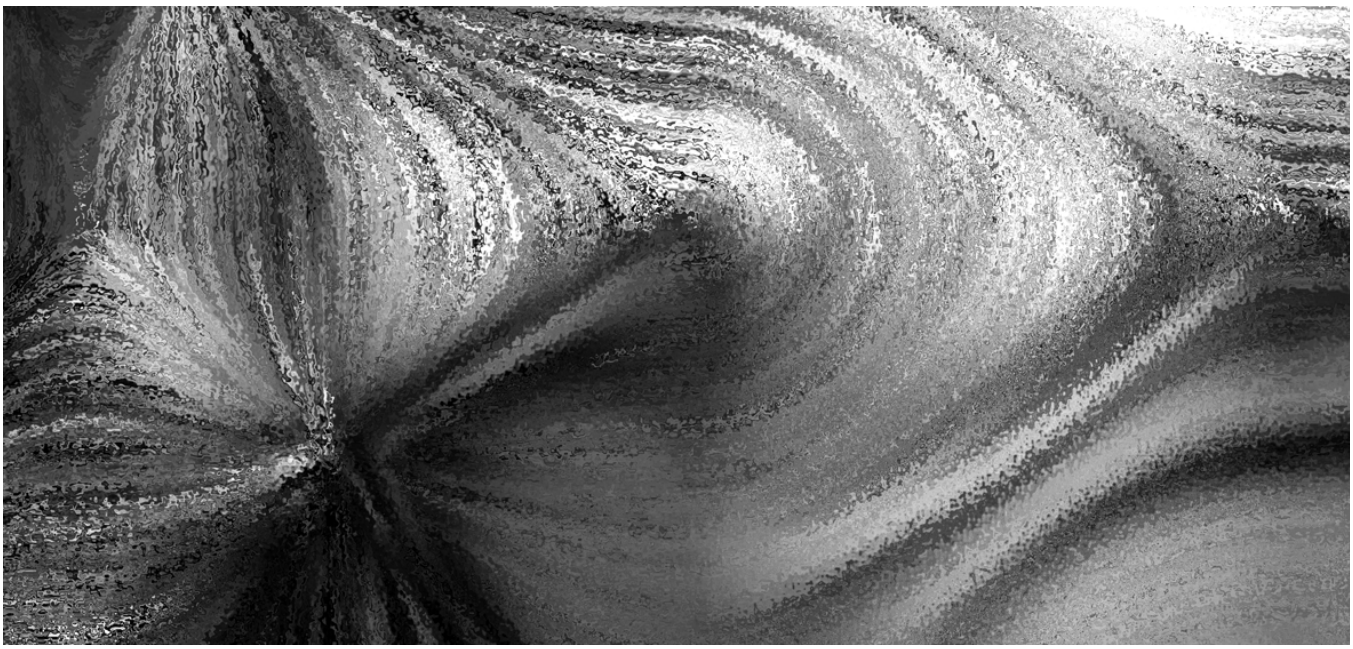
$$\frac{\text{Work done or}}{\text{Energy output in Joules}} = 9.8 \times \text{Mass in kg.} \times \text{Vertical distance in metres}$$

$$\text{Power output in Watts} = \frac{\text{Energy output}}{\text{Time in seconds}}$$

2.6.4 Validity of Power Tests

It is doubtful whether these power tests provide valid measures of 'power' or 'energy sources'. The Stair Test is significantly biased by the subject's body weight; the Jump Tests do not take body weight, length of levers or other significant variables into account; and mechanical factors such as pedal crank length, seat height, and inertia of the flywheel, all influence the estimation of power production on the cycle ergometer. Thus, these tests are only estimating external power output, not actually measuring the capacity of the physiological processes involved.

3 Assignments and Solutions



3.1 Assignments

These questions are designed to help you work through the material , and to provide you with a measure of your understanding of the subject.

A wide variety of styles of question are used; for example multiple choice, matching pairs, multiple completion, structured and essay; each designed to assess different levels of understanding, and to maintain interest. Some will also provide experience of the types of question found in most examinations.

Solutions are on sheets 65 & 68.

Multiple Choice Questions

For each of the following questions, choose the **ONE** response which best answers the question.

1 **Which of the following statements relating to the measurement of the pulse is correct?**

A The position of the subject makes no difference to the pulse rate.

B The pulse rate is not simply related to the heart rate.

C It is best to count the pulse rate at the wrist in the left arm.

D It is best to count the pulse in the neck.

2 **Which of the following statements relating to the measurement of the blood pressure is correct?**

A The conditions under which blood pressure are measured do not affect the blood pressure as long as the subject is at rest.

go to answer page

B Electronic equipment for measuring blood pressure is as valid and reliable as the mercury manometer.

C Anything greater than 120/ 80 mm Hg represents high blood pressure.

D Anxiety associated with its measurement can raise the blood pressure.

3 **With regard to the use of the spirometer, which of the following statements is NOT correct?**

A If the chamber is filled with air, and this is continually rebreathed, the amount of carbon dioxide (pCO_2) would gradually increase.

B If a carbon dioxide absorber is incorporated in the tube returning the exhaled air to the chamber, then the pCO_2 in the chamber will not rise.

C Lack of oxygen in the absence of CO_2 has little effect on the ventilation rate.

D The spirometer can be used to measure breathing rates, volumes, and carbon dioxide consumption.

Multiple Choice Questions

For each of the following questions, choose the **ONE** response which best answers the question.

4 **With regard to the Vital Capacity Trace shown in Figure 5, which of the following statements is NOT correct?**

A The Timed Vital Capacity or Forced Expiratory Volume (FEV) is determined by taking a maximum inspiration and exhaling as hard and completely as possible.

B About 85% of the vital capacity can be exhaled in one second by an adult.

C The maximum voluntary ventilation is the volume of air that can be breathed in 15 seconds of forced rapid and deep breathing multiplied by 4.

D Complete expiration of the expiratory reserve volume gives a direct measure of the total lung capacity.

go to answer page

5 **Which of the following statements, referring to the use of breath volume bags, is NOT correct?**

A A Douglas Bag allows expired air to be collected over longer periods of time.

B A Douglas Bag allows more freedom of movement during exercise than the spirometer.

C Measurement of the vital capacity always requires a valved mouthpiece in conjunction with a breath volume bag.

D For the correct use of the Douglas Bag a valved mouthpiece must be used.

6 **Which of the following statements, referring to Section 1.4 Miscellaneous Measures, is NOT correct?**

A Skin fold callipers provide an accurate measure of total body fat.

B The grip test is a crude measure of overall strength.

C Trunk strength is estimated from the number of correctly executed sit ups performed in 30s.

D Strength endurance is estimated from the time a bent arm hang can be maintained.

Matching Pairs Questions

For each of the following exercises, a list of four possible answers, labelled **A, B, C,** and **D** are provided. Several questions relating to these follow, and one of the alternative answers must be chosen for each question. Each of the four alternative answers **A – D** may be used once, more than once, or not at all to answer these questions.

---

7 **Listed below are four methods of exercising at standard work rates in a controllable and reproducible way.**

A Step test.

B Shuttle run test.

C Cycle ergometer test.

D Sargent vertical jump test.

Which of these tests:

i removes the complication of body weight from the testing procedure?

go to answer page

ii measures alactic power output?

iii is progressive and maximal?

iv involves the greatest degree of agility?

---

8 **Listed below are four measures of fitness.**

A Maximal aerobic capacity (VO_2 max).

B Anaerobic threshold (OBLA).

C Alactic power output.

D Anaerobic energy yield

Which of these:

i gives an indication of endurance capabilities?

ii gives a measure of the current state of endurance training?

iii can be measured using the Sargent vertical jump?

iv can be measured using the Wingate test?

Matching Pairs Questions

For each of the following exercises, a list of four possible answers, labelled **A, B, C,** and **D** are provided. Several questions relating to these follow, and one of the alternative answers must be chosen for each question. Each of the four alternative answers **A – D** may be used once, more than once, or not at all to answer these questions.

---

9 **Listed below are four criticisms of various fitness tests.**

A 30 seconds of flat out effort on the cycle ergometer will not exhaust the anaerobic capacity.

B Allowance must be made for the reduction of maximum heart rate with age.

C Is particularly dependent on the motivation of the subject.

D Is not as valid or reliable as cycle ergometer tests.

Which of these most applies to the:

i shuttle run test?

go to answer page

ii Wingate test?

iii estimation of maximal aerobic capacity from sub-maximal tests?

iv step test?

---

10 **Listed below are four ways in which the box-type spirometer can be set up.**

A With air in the float and no carbon dioxide absorbent.

B With air in the float and a carbon dioxide absorbent.

C With oxygen in the float and a carbon dioxide absorbent.

D With 60% oxygen and 40% air in the float, and a carbon dioxide absorbent.

Which of these would:

i be potentially hazardous within a few minutes, and result in a raised ventilation rate?

ii result in no change in the pO_2 and the pCO_2 in the float.

iii result in an increase in the pCO_2 in the float.

iv extend the duration of the exercise, but avoid problems of oxygen toxicity?

Multiple Completion Questions

In the following questions, three alternative statements numbered i, ii and iii are given.

Consider carefully which is/are correct and then choose one of the following alternatives.

A If **i, ii** and **iii** are correct.

B If **i** and **ii** only are correct.

C If **ii** and **iii** only are correct.

D If **i** only is correct.

E. If **iii** only is correct.

---

11 **With regard to blood pressure and its measurement.**

i The difference between the systolic and diastolic pressure is known as the 'pulse pressure'.

ii The 'pulse pressure' gives an accurate estimate of the stroke volume of the left ventricle.

go to answer page

iii The diastolic pressure is always higher than the systolic pressure.

---

12 **With regard to the use of the Box-type spirometer.**

i When the subject breathes in the chamber moves down.

ii When the subject breathes out the chamber moves up.

iii The chamber may be filled with air or oxygen.

---

13 **In the measurement of air flow using a pocket spirometer an indication of the power of expiration is obtained, this is:**

i related to the resistance to air flow in the respiratory system;

ii related to vital capacity;

iii of less significance than vital capacity in terms of lung function.

---

14 **The main criticisms of the step test are that:**

i correct stepping technique is difficult to maintain;

ii stepping efficiency is affected by the length and proportion of the legs;

iii body weight is an uncontrolled variable.

Multiple Completion Questions

In the following questions, three alternative statements numbered i, ii and iii are given.

Consider carefully which is/are correct and then choose one of the following alternatives.

A If **i, ii** and **iii** are correct.

B If **i** and **ii** only are correct.

C If **ii** and **iii** only are correct.

D If **i** only is correct.

E. If **iii** only is correct.

---

15 **The main criticisms of the shuttle run test are that:**

i a certain amount of agility is involved;

ii it is a maximal test so motivation of the subject can influence the results;

iii differences in body size and weight are not allowed for and will influence the results.

go to answer page

---

16 **The main criticisms of power tests are that they:**

i are sub-maximal and therefore inaccurate;

ii do not discriminate between males and females;

iii only estimate external power output, not the actual capacity of the physiological processes involved.

---

17 **The conditions under which basal metabolism should be measured are:**

i the subject should be lying down, or at least seated and relaxed;

ii food should not have been taken for 18 - 24 hours before the test;

iii the external temperature should be about 20°C, and should be the same for all the subjects tested.

Multiple Completion Questions

In the following questions, three alternative statements numbered i, ii and iii are given.

Consider carefully which is/are correct and then choose one of the following alternatives.

A If **i, ii** and **iii** are correct.

B If **i** and **ii** only are correct.

C If **ii** and **iii** only are correct.

D If **i** only is correct.

E. If **iii** only is correct.

---

18 **Maximal tests of physical performance are:**

i potentially hazardous to some subjects;

ii depend upon the motivation of the subject;

iii limited by the problem of determining when maximum effort has been made.

go to answer page

---

19 **Sub-maximal tests of physical performance require:**

i assumptions to be made about the maximum heart rate;

ii assumptions to be made about the resting heart rate;

iii continuous analysis of oxygen uptake.

---

20 **Scores achieved by growing youngsters on fitness tests are useful in order to:**

i compare their scores with other youngsters of the same age;

ii to predict their future physical capabilities;

iii to see how the individual develops over time.

---

21 **The main argument(s) against age group sports e.g. Under 14 etc is that:**

i there is a wide range of different maturation rates at any one age;

ii late developers may become even more self-conscious as a result of their relative lack of success;

iii success as a result of early maturation can raise false hopes, which when not realised at maturity can lead to disillusionment with sport in adult life.

Structured Questions

22 **Examine the spirometer trace in Figure 5 and answer the following questions.**

i What is the vital capacity of this subject?

ii What information is missing from the diagram that would enable the forced expiratory volume in one second to be calculated?

iii Calculate the approximate total lung capacity of this subject.

iv Time your own breathing rate at rest, and estimate approximately what period of time is represented by this trace.

23 **Using the information in Section 1.3 on the measuring of breathing, and your own knowledge, give concise answers to the following questions.**

go to answer page

i What is meant by the term 'closed system' when referring to a subject being tested on a box-type spirometer?

ii What is the danger of continually rebreathing air in the chamber without a carbon dioxide absorber?

iii If the chamber is filled with oxygen and a carbon dioxide absorber is incorporated in the tube returning exhaled air to the chamber, why is the pCO_2 not increasing, nor the pO_2 decreasing?

iv How is the 'minute volume' calculated?

Essay Question

Essay questions are designed to test facts, and also the ability to select and organise relevant material and to present it in a logical manner.

In addition to scientific content, marks are awarded for the understanding of the topic and therefore the relevance of the answer to the question, the range of material included, and the ability to communicate the information clearly in a well structured essay. Thus there can be no single perfect answer to an essay style question. There will always be a subjective element in the marking that can never be completely standardised.

A well structured essay will include a brief introduction, with individual points developed in separate paragraphs. If the question requires some discussion and a statement of your opinion on an open-ended problem, then the essay could conclude with a brief summary paragraph. Any diagrams used should be relevant, and an integral part of the essay, they should not simply duplicate what has been written.

The sample essays provided are not 'model' answers as such, but simply examples to illustrate what might be achieved by a good candidate under examination conditions.

go to answer page

24 **Give an account of the limitations of the testing of physical performance without the use of sophisticated, continuous direct measuring electronic equipment.**

3.2 Solutions

Answers to Multiple Choice Questions

1	C	2	D	3	D	4	D	5	C	6	A

Answers to Matching Pairs Questions

7	i	C	ii	D	iii	B	iv	B	
8	i	A	ii	B	iii	C	iv	C	
9	i	C	ii	A	iii	B	iv	D	
10	i	A	ii	C	iii	A	iv	D	

Answers to Multiple Completion Questions

11	D	12	A	13	D	14	A
15	A	16	E	17	A	18	A
19	D	20	E	21	A		

Structured Answers

22

i $14 \times 250\ cm^3 = 3500\ cm^3$.

ii Time in seconds along a horizontal axis

iii Indirect methods indicate that the total lung capacity is approximately 6 times the expiratory reserve volume, which here equals about 1050 cm^3. Therefore $6 \times 1050\ cm^3 = 6300\ cm^3$.

iv Average breathing rate at rest is about one breath in and out (a breathing cycle) every 4 seconds, ie 15 per minute. The normal breathing cycles shown on the trace would therefore take about 12 seconds. This distance represents half the trace, therefore the total time represented by the trace equals approximately 24 seconds.

23

i A 'closed system' here refers to the fact that there are no connections or leaks between the air in the subject's lungs and the apparatus, and the outside air.

ii The amount of carbon dioxide (pCO_2) would gradually increase and oxygen (pO_2) decrease.

iii The pCO_2 is not increasing because the exhaled CO_2 is being absorbed by the CO_2 absorber before it reaches the chamber. The pO_2 is not decreasing, as the pO_2 refers essentially to the proportion O_2 present in the chamber, although the volume of O_2 is decreasing it remains pure O_2.

iv The 'minute volume' is calculated by multiplying the tidal volume by the ventilation rate per minute.

Example Essay for Question

24

The main limitations of the testing of physical performance without sophisticated, direct continuous electronic measuring equipment, are of validity and reliability. Validity refers to whether the tests are actually measuring what they claim to be measuring, and reliability refers to whether the tests will give consistent results on repeated trials.

As most tests at this level are indirect, ie not directly measuring what they claim to be measuring, they are generally not valid. For example, in the absence of the continuous and direct measurement of oxygen uptake, maximum aerobic capacity is tested for by measuring heart rates under different conditions of exercise, e.g. step test, shuttle run test, treadmill tests, cycle ergometer PWC_{170} test; and the extrapolation from these via tables or nomograms is used to obtain an estimate of maximum oxygen uptake or aerobic capacity.

Although there is a relationship between heart rate at different sub-maximal levels of exertion and oxygen uptake, the relationship tends to break down at or near maximum heart rates. Furthermore, sub-maximal tests, which are designed to avoid the problems of maximal tests, depend crucially on an accurate estimation of maximum heart rate, which is fraught with inaccuracies due to individual variation, age, and training history.

The commonly applied formula estimates maximum heart rate in beats per minute (bpm) at (220 - age in years), e.g. 195 bpm for 25 year olds; however, maximum heart rate varies by as much as +/- 10 beats between individuals of the same age. It has been suggested that if you wish to avoid over-estimating VO_2 max by as much as 20%, then it is best to 'underestimate' maximum heart rate by up to 10 bpm.

continued....

continued....

When different tests are used to estimate the same measure, such as maximum aerobic capacity, or power, different results are obtained due to the different size of the muscle groups being used. Clearly there are many problems here which could lead to significant inaccuracies.

Therefore it can be seen that it would be necessary to measure oxygen consumption directly to obtain valid measures of maximum aerobic endurance. Similarly, power tests are only estimating external power output, not actually measuring the capacity of the physiological processes involved.

The fact that practice in the test procedure itself can lead to rapid, dramatic and specific improvement in test scores, raises questions of reliability. Not only might test scores of the same individual improve through practice, without any real increase in 'fitness', but conceivably they might well get worse for a variety of reasons not directly related to 'fitness', for example increased anxiety beyond the optimum level for physical performance, for whatever reason, will result in reduced test scores. As it is impossible to control all the variables which affect a human being, then it is equally impossible to claim to be testing just one aspect of the subject's status in isolation from the rest. These limitations could be overcome to a certain extent by repeating tests under standardised conditions and quoting mean or average scores.

If the subjects are exposed to each other, or an audience, whilst under test, interaction will influence results, especially in maximal tests, where motivation is so important. Some may deliberately under-achieve in these circumstances, and the constant comparison of children on the basis of test scores will affect those who genuinely score low in a negative manner. If the measurement of physical performance or 'fitness testing' emphasises social comparison it may undermine the subject's physical self-esteem and therefore subsequently affect their attitude to exercise for the rest of their life.